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FINAL REPORT ON DEVELOPMENT OF EMERGENCY INTRAVEHICULAR SPACESUIT (EIS) ASSEMBLY

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National Aeronautics and Space Administration
Crew Systems Division
Lyndon B. Johnson Space Center
Houston, Texas 77058

John F. Rayfield
John F. Rayfield, Project Engineer

Homer D. Reihm
Homer D. Reihm, Manager
Space Suit Programs

ILC INDUSTRIES, INC.
350 PEAR STREET
DOVER, KENT COUNTY, DELAWARE 19901

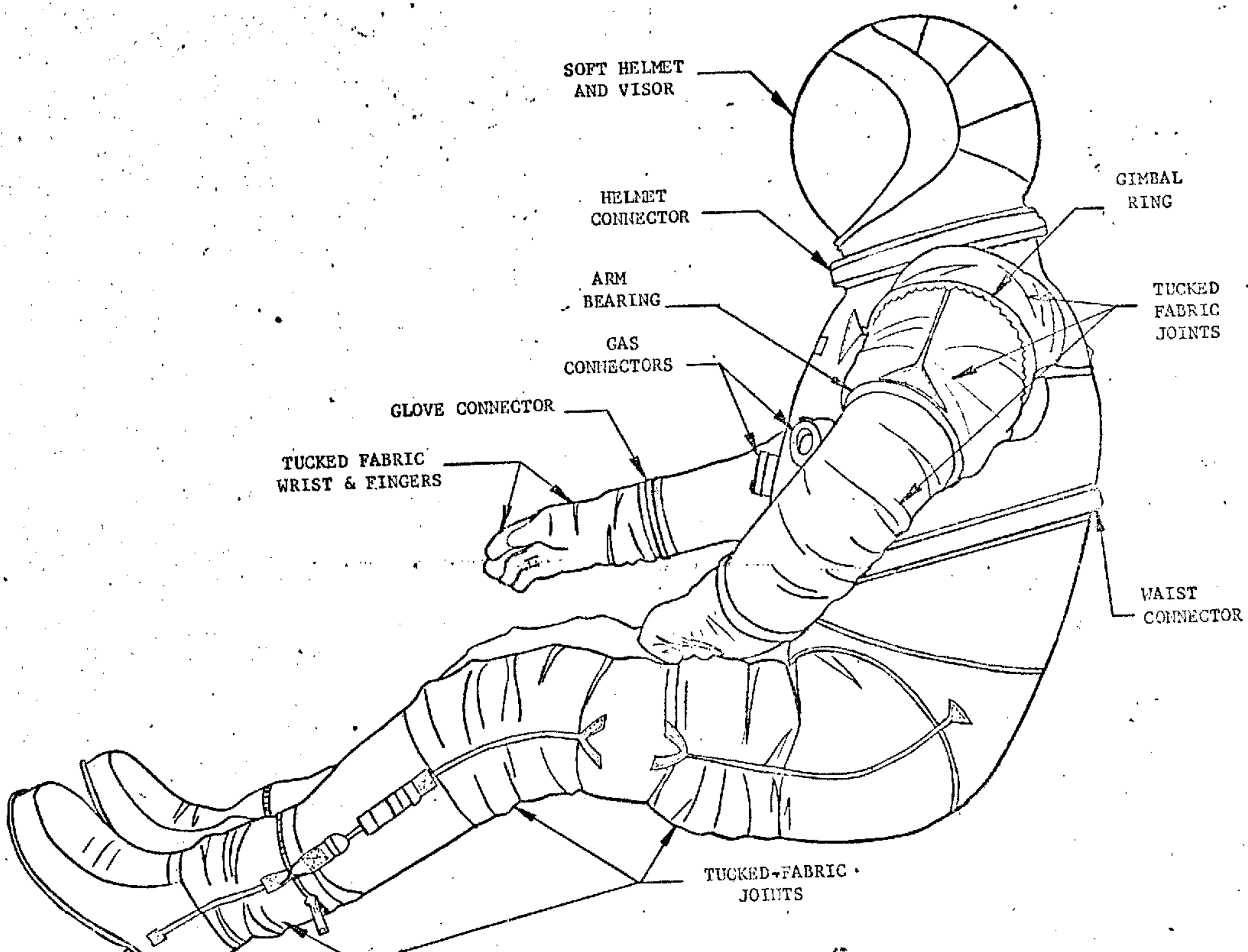


FIG 1 - EIS FINAL CONFIGURATION

1.0 INTRODUCTION

Under NASA Contract NAS 9-12995, a program was undertaken to develop and test two prototype pressure suits to operate at pressures up to 413 mm Hg (8.0 PSIG). The units were designated Emergency Intravehicular Spacesuits (EIS). This report covers the performance requirements, the design evolution, testing performed, problems encountered, and final EIS configuration.

2.0 DESIGN REQUIREMENTS

Specific design requirements are summarized below.

2.1 Pressure

Normal operating, 413 mm Hg (8.0 PSIG); structural, 16 PSIG; non-catastrophic failure, 20 PSIG.

2.2 Mobility

Joints to be located in elbow, shoulder, thigh, knee, and ankle. As a design goal, mobility envelope to be compatible with emergency fly-back capability in a seated configuration.

2.3 Ventilation System: Pressure Drop and CO_2 Removal

Pressure drop through the vent system not to exceed 9.14 cm (3.6 inches) of water with a flow rate of 198 LPM (7 ACFM) of 77° F (25° C) air at a suit pressure of 413 mm Hg. Partial pressure of CO_2 in the oro-nasal area not to exceed 7.6 mm Hg at 198 LPM (7 ACFM) and metabolic rate of 252 Kg-Cal/Hr. (1000 Btu/hr.).

2.4 Helmet

Collapsible, soft shell and visor. Sufficient visual field and optical quality to see and read all instruments required to perform an emergency fly-back.

2.5 Gloves and Connectors

Provide sufficient pressurized mobility to actuate switches and other flight controls, while also providing long-term comfort for unpressurized wear.

2.6 Communications and Bio-Instrumentation

These systems to be GFE Apollo/Skylab type; prototype EIS to incorporate mounting and routing provisions.

2.7 Weight

Target weight of less than 5.5 kg (12 pounds).

2.8 Flammability

Materials to meet the flammability requirements of NASA-JSC Document D-NA-002, except the cabin atmosphere shall be nominal sea-level (760 mm Hg, 80% N_2, 20% O_2).

2.9 Sizing

First prototype EIS to be custom-sized for a NASA-designated subject; second prototype to be sized to a standard size per NASA direction. A standard sizing program to be generated, based on suit configuration and crew anthropometry.

2.10 Comfort

Acceptable comfort for 8 hours unpressurized wear and 5 hours pressurized wear.

2.11 Donning

Unassisted donning by the crewman to be accomplished in less than 5 minutes, including preparation and connection to the vehicle ECS.

2.12 Leakage

Not to exceed 400 SCC/min. at 413 mm Hg at delivery. As a design goal, not to exceed 1000 SCC/min. during the service life of the suit.

2.13 Service Life

Equivalent to a mission of one year's duration, including preflight crew training, testing, and daily donning and doffing.

3.0 PROGRAM STRUCTURE

The EIS Program consisted of four phases, described below.

Phase A: This phase consisted of a detailed design and configuration analysis of state-of-the-art and advanced suit systems/components for applicability to the EIS requirements. Materials and components were subjected to testing and evaluation; this effort culminated in a report and recommendations for the Phase B prototype configuration.

Phase B: This phase consisted of the fabrication and test of sub-assemblies and components for incorporation into the Phase B prototype, and final fabrication of the Phase B prototype. Also included in this phase was the generation of the DVT Plan and Procedures and a sizing plan.

Phase C: Phase C consisted of design verification testing of the Phase B prototype EIS. This included cockpit evaluations, comfort evaluations, manned cycle testing, and mobility envelope measurements. Also included was the preparation and submittal of the Phase C DVT report, which included the Sizing Program.

Phase D: Phase D consisted of the fabrication of a second EIS, based on the results of the Phase "C" DVT.

NOTE: This program logic was not followed precisely: due to design problems uncovered during DVT of Phase B EIS 001, and numerous reworks and over-pressure tests, it was decided that more meaningful data would be obtained by performing the final DVT on the Phase D EIS 002.

4.0 TECHNICAL EFFORT

4.1 Phase A/Configuration Baseline

This is defined by the Phase A design and configuration report, excerpts of which are included in Attachment A, "8.0 PSI EIS DVT Configuration Change Summary".

4.3 Phase B Prototype Design Evaluation

The development efforts expended during Phase "A" were culminated in a review with NASA personnel at JSC. During this review ILC presented progress and problems to date. Demonstrations of the tucked fabric unilateral joints were conducted and material test data were presented. During this meeting several important decisions were made affecting the design of the Phase "B" prototype suit. It was decided to incorporate the tucked-fabric concept for the unilateral joints and to emphasize the concept in developing the shoulder, hip and waist. A gimballed, tucked-fabric shoulder was considered feasible and selected as prime candidate for the Phase "B" prototype. However, alternate design concepts, such as the 2-bearing shoulder, were continued as back-ups.

The decision to use a hard disconnect for the waist was based primarily on the inherent low reliability of zippers. A study was performed for waist disconnect sizing, location and minimum bulk cross-section. It was also decided at that time to use an Air Force type helmet connector to facilitate possible use with an ejection seat/conformal helmet configuration.

Following the Phase "A" review, efforts were continued to design an acceptable soft facepiece although progress to date had been discouraging due to the lack of acceptable materials. The shape and size of the helmet were accepted by NASA personnel during the meetings. The boot design with neoprene sole and heel was firmed but it was requested that ILC investigate a PRD-49/ epoxy laminate for the sole stiffener.

The glove design at this time had not progressed as far as some other areas but it was decided that tucked-fabric fingers and wrists were favorable approaches.

Subsequent to the Phase "A" design review, work continued from November of 1972 through April of 1973, culminating in the shipping of the Phase "B" prototype suit in April. A synopsis of the effort in each area is presented in the following paragraphs.

4.2.1 Elbow and Knee. The elbow and knee design conceived during the Phase "A" was finalized, tested, and installed in the first prototype suit. During this period a PRD-49 elbow was constructed and bench-cycled 100,000 times without failure. An attempt to use 3 oz. PRD-49 failed cycling because of seam pull-out. Use of the 3 oz. PRD-49 for restraint fabric was therefore discontinued. Early attempts at knee fabrication using a 5 oz. PRD-49 fabric also resulted in seam pull-out, but improved longitudinal seams were developed and a knee was bench-cycled 124,000 cycles without failure.

4.2.2 Shoulder. Considerable effort was expended during Phase "B" to develop a gimballed shoulder. The final shoulder joint design provides 150° of movement in the lateral medial plane and ± 30° of movement in the sagittal plane (which also provides additional cross-reach capability). This range was achieved with primarily soft components except for a low profile stainless steel gimbal ring.

4.2.3 Hip, Thigh and Waist. The original concept for waist and hip mobility was a tucked-fabric waist and hip. Early evaluations with a NASA prototype IV suit, in a Shuttle Mock-up cockpit proved that this configuration was unacceptable. Later evaluations of waist mobility indicated that this joint was an unnecessary complication in an IV emergency suit. It was concluded to configure the suit in a sitting position with sufficient leg mobility to operate foot pedals and allow the crewman to straighten up for seat egress/ingress and contingency transfer. The concept finally designed after several successively improved mock-ups was a single-axis, tucked-fabric thigh joint mounted in a seated-position lower torso.

4.2.4 Boots. The boot configuration, although basically complete at the Phase "A" review was finalized during Phase "B". The PRD-49 sole stiffener suggested at the review was utilized and fabrication techniques were optimized. The ankle joint failed after approximately 60,000 bench-cycles at 413 mm Hg, but was considered adequate since 10,000 cycles was the design requirement. Since it allows for convenient replacement of boots, a roll-seal at the upper boot-lower leg interface was pursued. Attempts at a leakage-free and reliable roll-seal were not successful; hence, a zipper and cemented joint were selected for the Phase "B" suit. Lower leg length adjustment capability was accomplished by use of soft goods sizing "links" incorporated in the longitudinal restraint webbing.

4.2.5 Helmet. The most difficult problem of the helmet development was in forming the soft visor. Both ILC and Airlock, Inc. were involved in attempting to form a hemisphere of Regalite, Lucolite or Hedwin sheet. The basic problem was that the depth of draw necessary for the required shape caused a haze in the material, ruining the optics. The final solution was to press-polish several layers of Lucolite to a thickness of .100 and to draw an ellipsoid shape. The ellipsoid, when installed in a spherical helmet opening and pressurized, assumes a nearly spherical shape and optics are maintained. A possible problem exists in that the facepiece material permanently elongates at temperatures above 28° C (82° F) when under load. NASA has estimated that the facepiece can attain a surface temperature of 32° C (90° F) during worst case conditions in the Shuttle Craft. If the 32° C temperature is confirmed, some other material for the helmet facepiece, possibly polycarbonate, will have to be used.

4.2.6 Bearings. The EIS bearings were to be of simple design and minimal cross-section. Various bearing concepts were evaluated and found to be unacceptable because of either high torque or high leakage. After the break-through of the gimballed shoulder joint rendered a scye bearing unnecessary, effort was concentrated on the upper arm bearing, using as a basis the Apollo bearing. It was reasoned that identical cross-sections (or greater) with 17-4 PH stainless steel (twice the strength for twice the load) should be satisfactory. See Figure 2 for the Apollo arm bearing and Figure 3 for the EIS arm bearing.

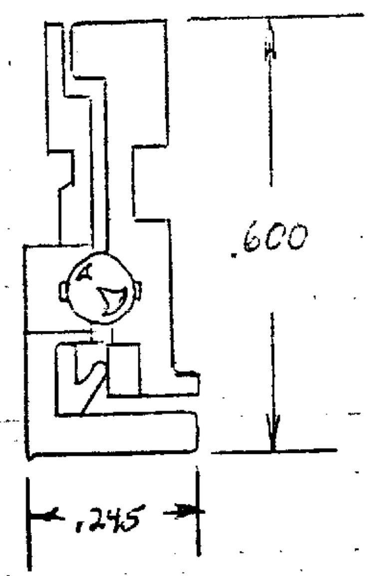


Figure 2
Apollo Bearing

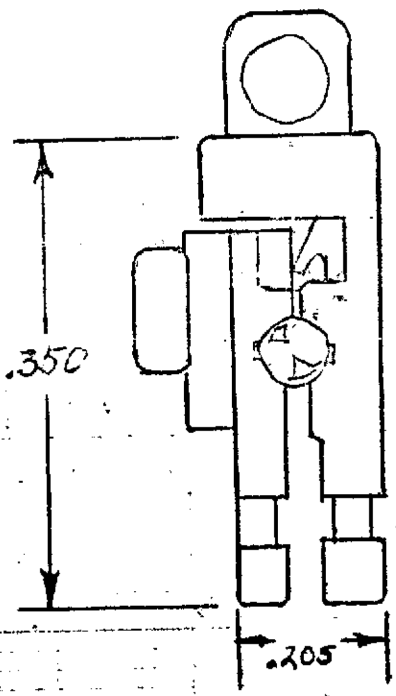


Figure 3
EIS Bearing

ARM BEARING CROSS-SECTIONS

The initial torques on this bearing were 1.15 - 1.28 Newton-Meters (18 - 20 inch/lb) at 413 mm Hg. Since the Apollo bearing torques were in the .45 - .64 N-M (7 - 10 inch-lb) range, it was decided to remachine the Teflon sealing surfaces to reduce the torque. After remachining, the torques were .64 - .77 N-M (10 - 12 inch-lb).

These bearings were also subjected to deflection tests under both 4- and 2- point loading conditions. The deflection was .127 cm (.050") at a load equivalent to 413 mm Hg. This means that high leakage of this bearing is likely <u>if</u> four (4) point loaded conditions exist at pressures above 413 mm Hg. However, two-point loading deflections are about .041 cm to .046 cm (.016" to .018") at 413 mm Hg (about the same as the Apollo bearing). Therefore, the axial restraints must be in line if the suit is subjected to pressures above 8 PSI.

An added feature of the EIS arm bearing is the "stitch-on" attachment technique whereby the bearing is drilled with .040-.060 in. diameter holes around the perifery and the restraint stitched into place with a hand stitching technique. Tensile strength tests (see Attachment "B") indicate this is a strong, reliable method of joining hardware to fabric.

4.2.7 <u>Entrance/Closure</u>. It was decided early in the program that pressure-sealing zipper closures were inherently unreliable for use in the EIS. A mechanical disconnect was chosen for the final EIS configuration. A sizing analysis for a mechanical disconnect located at the waist was conducted (See Table 1).

Following the Phase A Review, a sizing study was performed to select the dimensions for a mechanical waist disconnect. The results of this study are shown in the following tables and paragraphs.

TABLE 1

WAIST DISCONNECT SIZING - SHUTTLE

	Air Force 5th to 95th Percentile	Civilian 2.5 to 97.5 Percentile	Apollo History
Chest at Scye	35" to 43 1/4"	34 1/2" to 44"	36" to 43"
Waist Cir.	27" to 37 1/2"	27" to 39"	28" to 36 1/2"
Buttock Cir.	34 1/4" to 41 3/4"		34" to 40 1/2"
Hip Cir.		33 3/4" to 42 3/4"	
Hip Breadth	12.1 to 14.4	11.8 to 14.8	
Hip Depth	7.6 to 10.2	7.3 to 10.6	
Shoulder Cir.	41.6 to 49.4		
Chest Depth	8.0 to 10.4	7.7 to 10.7	
Shoulder Breadth	16.5 to 19.4	16.2 to 19.8	

Dividing the above ranges into equal increments, we get the following body dimensions as nominal for each waist ring.

	2 Size Rings				3 Size Rings		
			Circ.				
	"Small"	"Large"	Small	Large	"Small"	"Med."	"Large"
Chest @ Scye	39 1/2"	"44"	12.6	14	38"	41"	44"
Waist Cir.	33"	39"	10.5	12.4	31"	35"	39"
Buttock Cir.	38 1/2"	41 3/4"	12.3	13.3	36 3/4"	39 1/4"	41 3/4"
Hip Breadth	13 1/4"	14 1/2"			12 7/8"	13 5/8"	14 1/2"
Hip Depth	9"	10 1/4"			8 1/2"	9 3/8"	10 1/4"

CONCLUSIONS:

1. In 51 out of 58 Apollo crewmen, the chest circumference is larger than the buttocks circumference (usually 1 1/2" to 2"), suggesting that the internal half of the disconnect should be on the lower portion of the suit. (Of the remaining 7 crewmen, 3 had the same circumference chest and buttocks and the other 4 were within 1/2" of the same.)

2. The hip breadth and depth numbers suggest the major and minor dimensions of the elipse obtained by tilting a circular ring. The large dimensions suggest a 14 1/2" circle tilted until there is a minor (front to back) dimension of 10 1/4". However, such a ring tilted to 30° off horizontal gives a 12 1/2" front to back dimension, which is more reasonable.

3. Data on shoulder circumference with arms over the head is lacking, but this data seems to correspond with a disconnect outer half about 1 1/2" larger than inner half and with the 15" diameter hoop, tried with various subjects during a previous study.

As a result of this study, a 39.4 cm (15 1/2") inside diameter waist disconnect was selected. (The study indicates that two or three sizes would be practical; however, the largest size only was selected for this initial program.) This disconnect employs a breech-lock type locking mechanism.

4.2.8 Hardware Mounting. The usual hardware (e.g., gas connectors) mounting procedure used with the Apollo, and other pressure suits, has traditionally been to reinforce the area, punch holes for screws, caulk and clamp with screws. This procedure is highly reliable but makes the hardware difficult to remove and replace. Because of the thermoplastic nature of the bladder material (polyurethane), it was decided to integrally mold a reinforcement-sealing area into the suit wall, carefully controlling durometer of the area to guarantee a reliable, leakage-free seal. This was successfully fabricated and tested and is part of the final EIS suit design. As a result, the hardware may be removed and replaced innumerable times without affecting the integrity of the suit wall or requiring cleaning of the hardware.

4.2.9 Materials and Processes.

4.2.9.1 Restraint

The design of this suit restraint employs a new fabric made from PRD-49 Fiber (duPont "Kevlar"). This material is a proprietary duPont product. It has tensile strength in the neighborhood of 18-21 grams per denier, and low ultimate elongation. Extensive testing throughout the duration of this program has indicated that this is a viable material for the restraint of higher pressure space suits. However, further development is necessary to produce an optimum fabric weave. There are problems inherent in the low elongation characteristics such as stress risers, and seam strength lower than fabric tensile strength. Also, flex cycling characteristics are not optimum. The optimum design may lie in a blend with other fibers and/or a change in weave style. (See attachment "B" for detailed test data, and attachment "A" which contains a copy of the procurement specifications for the fabric used in the EIS.)

4.2.9.2 Bladder

Extensive testing was performed on the polyurethane bladder materials. Conclusions drawn from the testing indicate that unsupported polyurethane is an excellent material for the bladder of the suit, and it should yield a shelf life of at least seven or eight years. It is readily heat formable, easily sealed with RF sealing equipment, easily cemented to itself and other materials, has good abrasion and tear resistance, and high ultimate elongation. The material finally used in the Phase B and Phase D EIS was Union Carbide's Perflex "E" 101 film. Detailed test results on this material are presented in Attachment B.

Attachment B also provides a summary of other relevant materials and processes testing.

4.2.10 Vent System. Vent system development for the EIS suit began with an evaluation of the existing Apollo vent ducting in terms of weight, pressure drop characteristics, crush resistance, flex cycle life, vent terminations, and vent plenums. From this evaluation and from review of EIS requirements the following design requirements were established:

1. Materials must be spacecraft compatible.
2. Weight - less than 1.04 gm/cm (.07 lb/ft.)
3. Crush resistance - comparable to Apollo system - 13.57 Kg/cm^2 (193 lb/in^2).
4. Pressure drop - less than that of Apollo during all flow modes.
5. Cycle life - minimum flex life of 100,000 cycles when cycled 110° over a 5.75 cm (2.25 inch) radius.

With the above parameters established, a survey of tubing and duct vendors was conducted to establish the availability of an existing tubing or duct which would meet the established requirements. This survey disclosed that none of the available commercially manufactured products would meet the requirements; furthermore, due to the unique application and minimum quantity requirements these same tubing and duct manufacturers would not commit to any development effort.

It was therefore necessary to design a flexible duct. Steel, aluminum, and nylon along with other materials were considered for use as spacers. Nylon was finally selected as the spacer material due to its light weight and ability to recover when subjected to crush tests. Several sample ducts were fabricated using Perflex "E" polyurethane inner sleeves, nylon spacer coils of a flat oval configuration, and various polyurethane outer coatings.

Evaluation of these early samples indicated excellent weight, pressure drop and crush resistant characteristics; however, the flex-cycle life was limited due to the polyurethane coatings. Further evaluation of polyurethane coatings resulted in the fabrication of a ventilation duct which meets all of the design parameters including flex-cycle life (100,000 cycles without degradation).

Vent system plenums (gas connectors) of the Apollo type were not acceptable for interface or termination of the new ventilation duct. Tooling was designed to fabricate plenums which could be vacuum formed from a thermoplastic material (Noryl). These plenums provided a minimum of pressure drop at the gas connectors and a hard interface point for the ventilation ducts.

Vent-system interfaces with the plenums and vent/hardware attach points were evaluated. The method finally selected was to use 1.6 mm (1/16") nylon pins to secure the duct to its interface and polyethylene shrink tubing to provide a seal at the interface and retain the pin(s) in position. Vent system interface at the neck plenum, and boot vent, was accomplished by adhesive bonding with N-136. A spacer was attached to the end of each arm vent so that it could extend into the glove and provide cooling for the hand area.

Several methods for attachment of the ventilation system to the suit wall were evaluated. It was required that the duct should be free to move between its constrained attach points, so as not to restrict mobility. Therefore, vent duct restraining loops were fabricated and secured to the bladder wall with velcro.

4.2.11 Gloves

4.2.11.1 Description. The principle component of the EIS glove is a PRD-49 fabric restraint incorporating a bi-axial tucked wrist and single-axis tucked-fabric fingers and thumb. The restraint is patterned so that all elements interface to produce a relaxed, mid-mobility range attitude.

A molded fiberglass palm restraint maintains conformity in the palm and distributes the axial load from the wrist joint. A molded fiberglass oval ring joins the two 90 degree opposed wrist joints to achieve omni-directional wrist mobility.

The glove bladder is a composite fabricated from dip-formed urethane fingers, metacarpal, thumb, and abbreviated hand bonded to a lower hand/wrist portion of .25 mm (10 mil) urethane film. The bladder is joined to the glove restraint at the finger tips, metacarpal, and wrist disconnect only.

4.2.11.2 Materials. In selecting the restraint material, the 3 oz. Kevlar fabric was first evaluated. The material was of adequate strength and would produce a lighter more flexible restraint. The relatively open weave of the 3 ounce fabric, however, was difficult to hold in the finger seams and was susceptable to snagging. The 5 ounce Kevlar fabric provided a much more durable restraint with acceptable weight and stiffness.

ILC initially considered the use of stainless steel in the palm restraint to minimize bulk. The cost and lead time to produce tooling to form the complex shapes was prohibitive for the design phase, however, and it was determined that adequate strength could be achieved with fiberglass without excessive bulk. In addition to a significant weight savings, the fiberglass components could be easily reproduced on inexpensive molds which in turn were quickly modified as the design progressed. Both the palm restraint and wrist gimbal were ultimately fabricated by hand layup of six plies of glass fabric and epoxy resin.

ILC investigated fabrication of these components with Kevlar fabric and epoxy and with a high-temperature flame-resistant poly-vinyl resin. Layups were also tried using the poly-vinyl resin with glass. None of these systems were found to have advantage over the glass/epoxy laminate, and caused a variety of problems in fabrication. The Kevlar fabric could not be thoroughly impregnated with resin with available processes. The parts also were extremely difficult to cut, drill or otherwise finish. The glass and poly-vinyl resin produced satisfactory parts, but the resin has extremely short gel time and was air inhibited. Both characteristics caused fabrication problems with no distinct improvement in properties.

4.2.11.3 Sizing. Sizing of the gloves is proposed to be accomplished by the creation of a large and small glove based on hand breadth. A proportionate adjustment would be applied to the circumference of the wrist, hand, finger and thumb diameters. Each glove size will be available in six finger lengths of 6 mm (1/4 inch) increments in length.

4.2.11.4 Production Adaptation. The glove was designed to not require any special skills in fabrication. All components of the same designated size are interchangeable. More sophisticated tooling would be recommended for laying up and trimming the fiberglass components, and for setting the eyelets and rivets used in final assembly. In addition, more effort is required to design and fabricate dip molds and dipping facilities for a fully formed seamless urethane bladder.

4.3 Phase C Design Verification Testing

Detailed reporting of the Phase C DVT is contained in a separate report (ILC Document No. 8852701152). This report also describes the complete Sizing Program.

4.4 Phase D Prototype Design Evolution

During the DVT, various design deficiencies became apparent, resulting in redesign and rework of Phase B EIS 001. These configuration changes were incorporated in Phase D EIS 002. The detailed history of these changes is contained in Attachment A ("8.0 PSI EIS DVT Configuration Change Summary", ILC Document No. 8852700151).

It was finally decided to rerun the cycle DVT on EIS 002, since 001 had been subjected to numerous reworks and 16 PSI proof pressures, which could possibly cause unrealistic failure modes. Figure 1 shows the final configuration of the EIS.

5.0 CONCLUSIONS

This program resulted in a significant advance in pressure suit technology. Specific areas of advancement include:

- Pressurized (8.0 PSIG) mobility greatly superior to existing flight suits, and advanced suits, operating at 3.5 - 5.0 PSIG.
- Simplified construction of mobility joints. All single-axis joints are made entirely of soft goods. Use of hardware, such as bearings and gimbal rings, was reduced to an absolute minimum.
- Elimination of metal cables, cable guides, pressure-sealing zippers, and rubber dipped goods, all of which have been marginal in reliability and/or shelf life in the past.
- Greatly reduced cost of fabrication of mobility joints.
- Rapid donning and doffing.
- Long shelf life (at least 8 years).

Maximum use was made of existing space suit hardware component designs that have proven themselves in the past, e.g., gas connectors, helmet connector, glove connector, hard waist -disconnect.

A considerable amount of experience was gained, and data generated, on the construction and use of soft goods (fabric, cord, tapes, etc.) made from Kevlar (PRD-49) fiber.

6.0 RECOMMENDATIONS

Recommended further action areas relative to the EIS include:

- Optimization of the Kevlar fabric construction, possibly including the use of a tri-axial weave.
- Use of an elliptical waist connector to reduce bulk at the waist and to reduce weight.
- Continued cockpit interface studies.
- Modification to interface with ejection seat and hard helmet.
- Investigate incorporation of a waist joint to enhance pressurized intravehicular mobility.
- Lightweight gimbal ring for the shoulder joint.

ATTACHMENT A

8.0 PSI EIS DVT CONFIGURATION CHANGE SUMMARY

Release Date ___________

8.0 PSI-EIS

DVT CONFIGURATION

CHANGE SUMMARY

ILC	NASA
Approved by: H. D. Reik EIS Program Manager	Approved by: ___________ JSC Safety Office
Approved by: John F Rayfield EIS Project Engineer	Approved by: ___________
Approved by: [signature] System Safety Officer	Approved by: ___________
	Approved by: ___________

Contract Number NAS-9-12995

CHANGE LOG

Authority For Change	Description of Change	CEI S/N Effectivity	Affected Page(s)

CONTENTS

8.0 PSI EIS DVT

CONFIGURATION CHANGE SUMMARY

During the course of the design verification testing (DVT) of the 8.0 PSI Emergency Intravehicular Suit (EIS) some problems were uncovered.

This report has been prepared to summarize these problems with descriptions of the design changes which were incorporated into the EIS to correct these problems.

The EIS Phase "A" report documents all the design and development effort which was utilized in the initial Phase "B" EIS delivered to NASA/JSC on 5/7/73. Excerpts from the Phase "A" report are included as Appendix "A" to substantiate the initial EIS Configuration.

Prior to delivery of the EIS to NASA/JSC several structural (12 PSIG), proof pressure (16 PSIG), and leakage tests (at 8 PSIG) were performed at ILC/Dover to verify the pressure integrity and safety of the EIS.

The EIS was received at NASA/JSC on 5/7/73. A predesign verification test review was conducted on 5/11/73 to review the EIS DVT Test Plan and Procedure, incorporate all necessary comments, and obtain approval signatures.

Appendix "B" lists those NASA and ILC personnel who participated in the test review meetings. A pre-verification test was initiated on 5/30/73 at the NASA test facility. This test consisted of a detailed visual inspection, a leakage test and structural test at 12 PSIG. After the selection of test subjects for the DVT, vent pressure cycling in accordance with the DVT test plan and procedure (ILC Document No. 8852701102) was initiated on 6/4/73. After 150 manned vent pressure cycles were completed, the right boot developed an audible leak. Inspection of the EIS boot revealed that the heat seal in the toe of the right boot bladder had separated. It was determined the separation was caused by a poor heat seal. This was resealed at NASA/JSC and a leakage and structural test (12 PSIG) was performed to verify structural integrity and manned safety.

On 6/7/73, the EIS was manned at 8.0 PSIG for 1/2 hour during a Space Shuttle orbiter mock-up interface evaluation. This same day the EIS was subjected to 350 additional manned vent cycles (total 500 manned vent cycles). On 6/8/73, 350 additional DVT manned vent cycles were performed (850 total manned vent cycles) when a small tear was noted on the front of the left panel of the suit brief at the groin line seam. It was decided by NASA/JSC and ILC that the suit would be returned to ILC/Dover for additional visual inspection of the total suit assembly and repair of the groin area.

The method of attachment of the EIS brief to the legs was reviewed by the ILC/Dover Design, Project, and Systems Safety Engineers. It was determined that a design change in the method of seam attachment at the groin line (where brief attaches to leg) was necessary. Figure 1 illustrates the seam attachment change made. The fabric in the front of the panel of the brief required replacement since it was torn. However, it was decided to replace the entire brief to insure the front of the right panel of the brief and other possibly weakened panels of the brief would not malfunction in future testing. As a result, the groin line seam was changed on both the left and right legs to the new configuration illustrated in Figure 1.

To verify the pressure integrity, a structural test (12 PSIG) was performed. After four (4) of the five (5) minutes required for the test duration had transpired, the right front shoulder restraint tape separated and the shoulder restraint material and bladder ruptured. Investigation revealed that the 1/4" wide flat tape, when flexed at a sharp angle, was loaded with excessive tensile loads on the outer yarns of the tape, causing progressive breakage. It was determined that a braided cord would be more compatible with the loading experienced in the shoulder, since minimal flexural loading would occur on the braided yarns. In addition, the braided cord consisting of an inner core and braided sheath exhibited superior tensile strength over the previously used 1/4" restraint tape. This was verified by Instron machine testing. The 1/8" braided cord was then subjected to the Military Standard Flexural Test for a 3/32" diameter steel cable (MIL-W-5424) and successfully passed (in fact, the cord showed no loss of tensile strength). As a result, the 1/8" diameter braided cord was installed as the restraint in both the left and right shoulder joints. A new upper torso shoulder bladder and upper restraint fabric was incorporated in the EIS during the shoulder restraint tape design change.

After successful structural (12 PSIG) and proof pressure (16 PSIG) tests, a manned test at 6.0 PSIG was performed by subjecting all EIS joints to approximately 1000 cycles. During this testing heavy man-induced loads were purposely imposed by the test subject (including thigh abductions). A structural (12 PSIG) and leakage test was performed on the EIS; the EIS was returned to NASA/JSC on 7/27/73.

On 8/1/73, Astronaut John Young donned and exercised in the suit at 5.75 PSIG for 10 minutes. DVT cycle testing was also continued on this date, and an additional 900 manned cycles at vent pressure (total 1750 manned vent pressure cycles) were completed.

On 8/2/73, 1300 manned cycles were performed on each joint at 8.0 PSIG and 350 additional (total 2100 manned vent pressure cycles) manned vent cycles were completed. During this testing, leakage developed in the lower portion of the arm. The malfunction was caused by the separation of a heat sealed bladder seam and was repaired with a patch over the seam on the same day. After curing of the patch, a leakage and structural (12 PSIG) test wasperformed and cycle testing was continued.

On 8/3/73, 1700 additional manned pressurized cycles (total - 3000 manned cycles at 8.0 PSI) and 1500 additional manned vent pressure cycles (total - 3600 manned vent cycles) were completed.

On 8/6/73, approximately one (1) minute of cycle testing at 8.0 PSIG had been conducted (36 additional manned pressurized cycles) when the right knee restraint tape broke and the knee joint restraint fabric parted. The subject was depressurized, and the EIS was returned to ILC/Dover for inspection and repair.

After examination of the failed knee joint at ILC/Dover, the decision was made to use a new axial restraint which would be stronger and less affected by flexural loadings than the 1/4 inch flat restraint tape.

A 1/8 inch diameter hollow braided Kevlar (PRD-49) sheath was selected as the new restraint after this flattened circular cross-section had demonstrated superior strength and ability to endure flexural loads. The sheath utilized was the same as on the braided cord used on the EIS shoulder joints. Tensile tests of the sheath resulted in a 960 lbs. breaking strength for an 8 inch sample.

The braided sheath was then sewn to a test model knee joint to verify the adequacy of the sheath and the method of attachment to the knee joint restraint material. The test model knee joint was then cycled at ILC/Dover on a bench cycle test apparatus for 100,000 cycles at 8.0 PSIG. No evidence of damage to the new restraint sheath or the axial restraint line was observed.

As a result of the above discussed testing, two new knee joints and restraints were incorporated onto the DVT EIS. The EIS urethane bladder in the knee area was inspected in detail and no evidence of damage was noted.

Inspection of the lower torso at ILC/Dover also revealed that the 1/4" axial restraint tape as well as the 3/4" wide anchor webbing in the inner thigh was beginning to separate. Investigation revealed that this was caused by excessive man-induced hip abduction loadings (which are not an EIS design requirement). As a result, this tape was also replaced with the 1/8" diameter braided sheath and new anchor webbing was added. A leakage and proof pressure (16.0 PSIG) test was then performed to verify proper operational and structural integrity. Although the 16 PSIG proof pressure test was successfully passed, material damage was noted at:

1. The left front panel of the brief at the groin line.

2. The right front shoulder at the point where the braided cord is stitched to the axial restraint line.

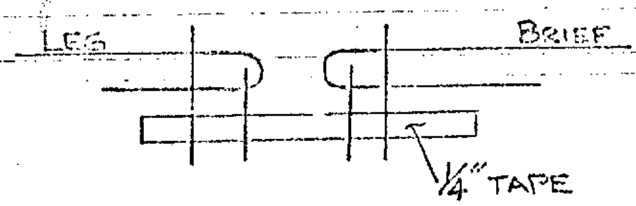
In order to verify the structural compatibility of the newly added restraint sheaths and to determine the impact of the previously noted material damage, a manned cycling test was conducted at 6.0 PSIG and run for 1000 cycles. The new braided sheath functioned well, and it was agreed by ILC personnel to be a successful modification. However, in the two areas noted to have material damage, slightly additional yarn damage was observed after testing. It was decided that these two areas (the left front panel of the brief and the right front shoulder) should be modified prior to additional manned pressure cycle testing at JSC.

Due to previous experiences with yarn damage in the brief at the groin line, the design of this area was investigated in detail. It was determined that wearing of the fill yarns of the brief at the groin line resulted only where the yarns were tangent to the curvature of the groin line. To prevent future tearing in this area, the direction of the weave for the left and right panels of the brief was rotated to move the point of tangency of the fill yarns to a location on the groin line where lower stresses exist. In addition, the brief was repatterned to relieve high stress areas on the groin line. This newly configured brief was incorporated into the EIS.

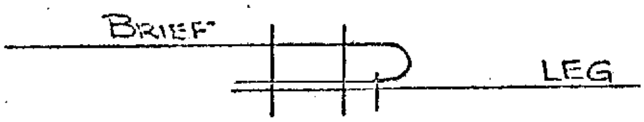
The slight yarn separation in the right front shoulder resulted from the attachment of the front restraint cord to the shoulder joint restraint fabric. This was corrected by removing the stitches which secured the center section of braided restraint cord to the restraint fabric and allowing it to float free with the ends attached using the same restraint cord anchor design. A new improved shoulder joint which has additional fabric and a new dart design was also added to the suit on the right side of the EIS only. After these modifications, structural (12 PSIG) proof pressure (16 PSIG) tests were performed on the EIS. After approximately three (3) minutes of proof pressure testing (16 PSIG), the restraint material (at the seam where the top of the left shoulder joint and the neck cone join) ruptured. This rupture also resulted in several tears of the urethane bladder in this same area. The failure resulted from fabric breakage in an area which had been reworked numerous times during the initial development of the suit. This was confirmed by the presence of numerous stitching holes in this seam area due to several shoulder joint changes.

As a result of this failure and the possibility that additional malfunctions may occur due to excessive high pressure cycling (16 PSIG) and the restitching of seams during the reworks described, it was agreed by ILC and NASA to terminate all further DVT testing of the EIS prototype S/N DVT-S001.

All future DVT testing will be performed with EIS prototype S/N DVT-S002 which will incorporate all the configuration changes discussed within this report.



NEW SEAM DESIGN



OLD SEAM DESIGN

GROIN LINE SEAM CHANGE

FIGURE 1

APPENDIX B

Attendees

EIS Predesign Verification Test Review - 5/11/73

1.	J. Kosmo	NASA-EC9
2.	J. Schlosser	NASA-EC9
3.	R. Minks	ILC/JSC
4.	J. Lewis	ILC/JSC
5.	R. Ewart	ILC/JSC
6.	G. Pitmann	NASA/Chief Test Support
7.	R. Roll	NASA/Tech.
8.	J. Kalk	NASA/Quality
9.	K. Grayson	ILC/JSC
10.	J. O'Donnell	ILC/Quality
11.	R. L. McLaughlin	NASA/Safety
12.	M. Dixon	NASA/Medical Tech.
13.	B. Lapham	ILC/JSC
14.	K. Vetter	NASA/Quality
15.	P. Bauchanan	NASA/M.D.
16.	W. Wachsler	ILC/Safety

EMERGENCY INTRAVEHICULAR SUIT

(EIS)

CONTRACT NAS 9-12995

PHASE "A" STATUS REVIEW

I. INTRODUCTION

This document contains the recommendations, supporting data, and discussion of open issues, pertinent to the design and configuration of the Emergency Intravehicular Spacesuit (EIS). The purpose of this document is to summarize the results of the development, testing, and evaluation conducted during Phase "A" of Contract NAS 9-12995, to make specific recommendations for the design and configuration of the first prototype EIS to be fabricated during Phase "B", to outline any areas of design not yet resolved, and to propose approaches to resolve these areas.

2.0 Recommended Configurations and Construction

Based on the testing and evaluation conducted under Phase "A", the EIS configurations recommended for the first prototype to be fabricated under Phase "B" is as follows:

2.1 Pressure/Restraint Layup: The restraint fabric to be PRD-49; 5.2 oz/yd^2 for larger cross-sections (e.g., torso), 2.9 oz/yd^2 for limbs/joints. Separate urethane film bladder in joints; laminated in selected areas, such as gas connector mountings.

2.2 Mobility Joints: The elbow, wrist, finger, thumb, hip/waist system, knee and ankle to be tucked-fabric (PRD-49) with separate urethane bladders. The shoulder to have a scye bearing and upper-arm bearing, with a single-axis joint (probably tucked-fabric) between. A three-bearing shoulder should also be considered.

2.3 Closure: Waist disconnect; either mechanical connector or hard rings with restraint zipper. Serious consideration should be given to a waist rotary bearing, if a mechanical connector is selected.

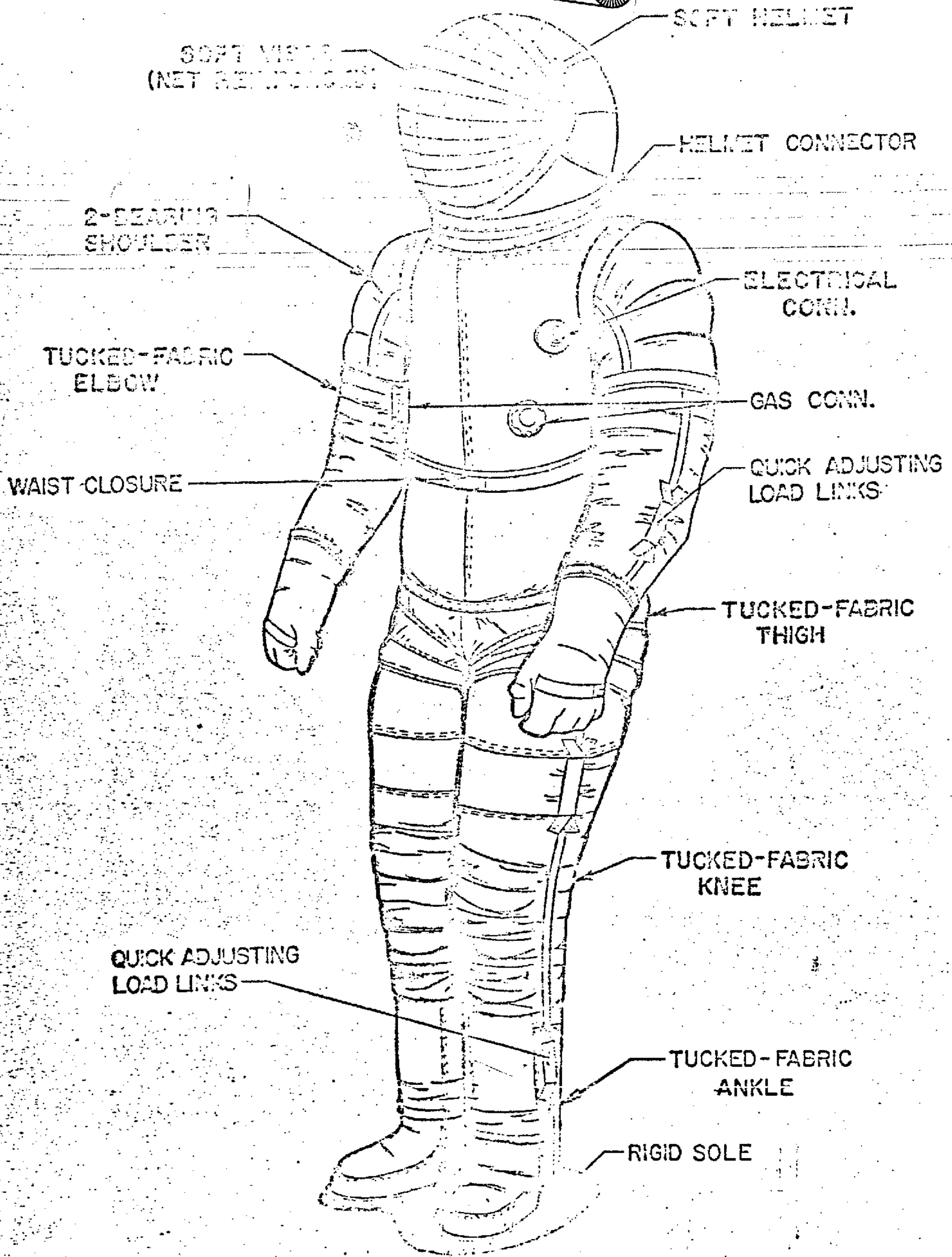
2.4 Vent System: Single inlet and outlet; nylon-coil, smooth-bore ducts; twin ducts to helmet, return ducts in arms and legs.

2.5 Helmet: 60-mil Regalite (Vinyl) soft visor supported by high-tenacity Dacron net; connector to be hard rings/O-ring/restraint zipper.

2.6 Boots: Rigid fiberglas insole, neoprene outsole and heel; axial restraint load line to be carried around bottom of boot.

2.7 Gloves: Tucked-fabric wrist (two (2) single-axis, gimballed); tucked-fabric fingers; hard palm restraint; tucked fabric thumb (single-axis). The need for a metacarpal joint must be established by in-cockpit evaluation.

2.8 Sizing: First prototype will be sized for Jack Mays, NASA/MSC. Quick adjusting links will be used in place of lacing cord/loop tape for vernier sizing of arm, leg, (both lower and upper) and possibly torso length.


ELECTRICAL CONN.
TUCKED-FABRIC ELBOW
GAS CONN.
QUICK ADJUSTING LOAD LINKS
WAIST CLOSURE
TUCKED-FABRIC THIGH
TUCKED-FABRIC KNEE
QUICK ADJUSTING LOAD LINKS
TUCKED-FABRIC ANKLE
RIGID SOLE

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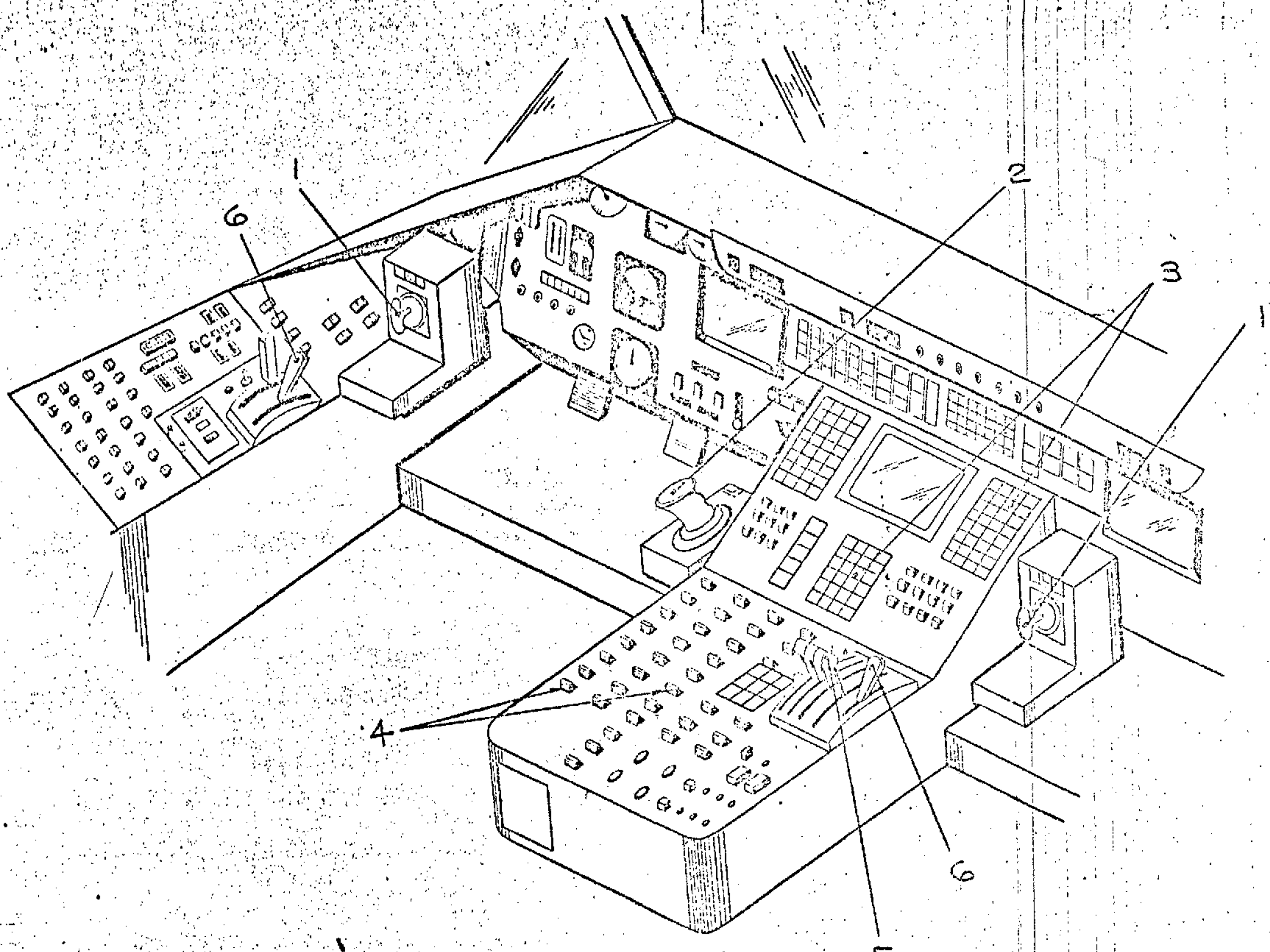
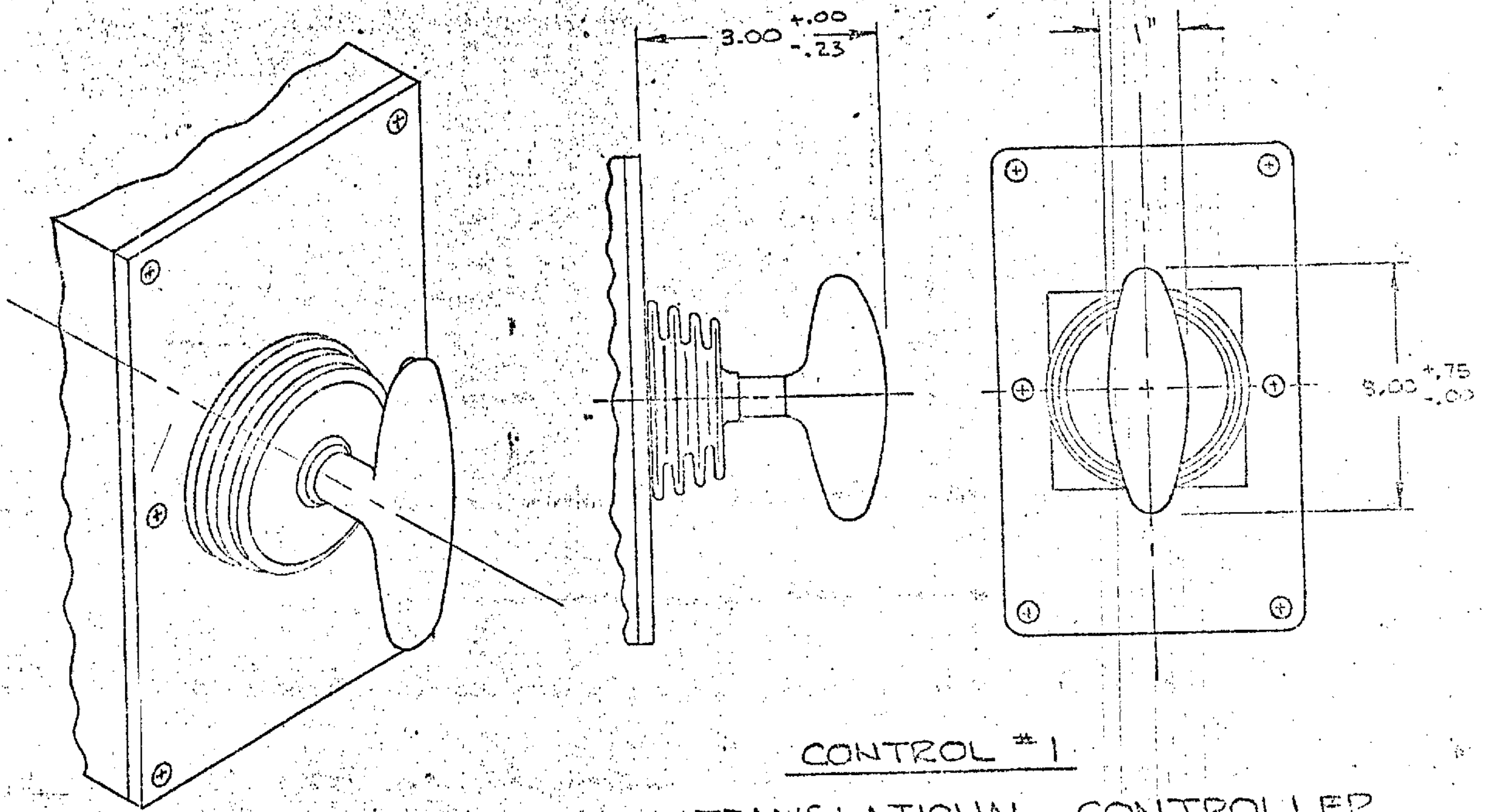
3.2 MOBILITY JOINTS

Mobility Requirements: Mobility requirements for pressure suits to fly or operate the Shuttle Craft were investigated by reviewing the Shuttle Orbiter cockpit mockup at North American Rockwell; Downey, California.

The attached sketches illustrate the recommended pressure suit mobility design requirements.

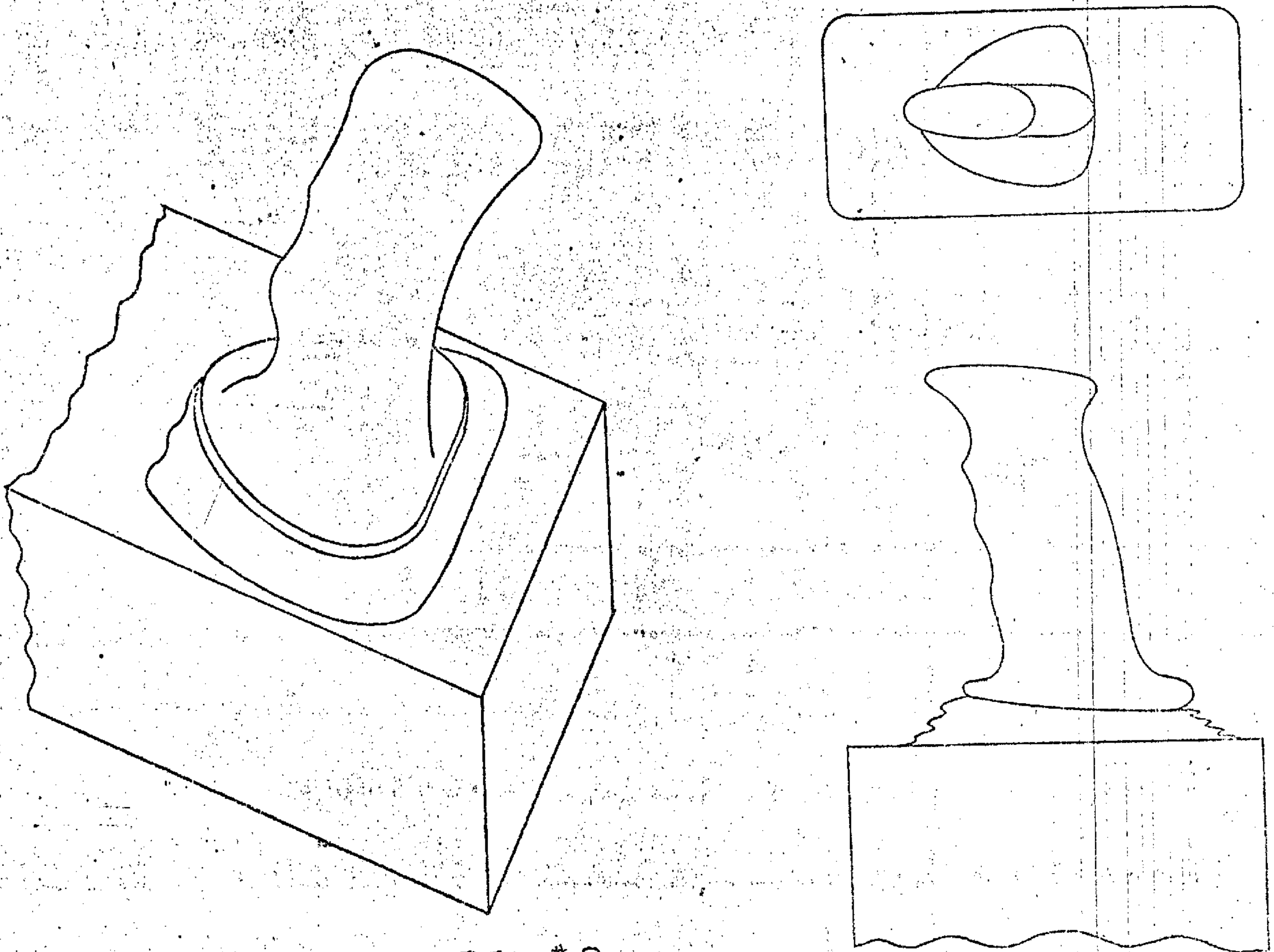


FLIGHT CREW STATION



CONTROL # 1

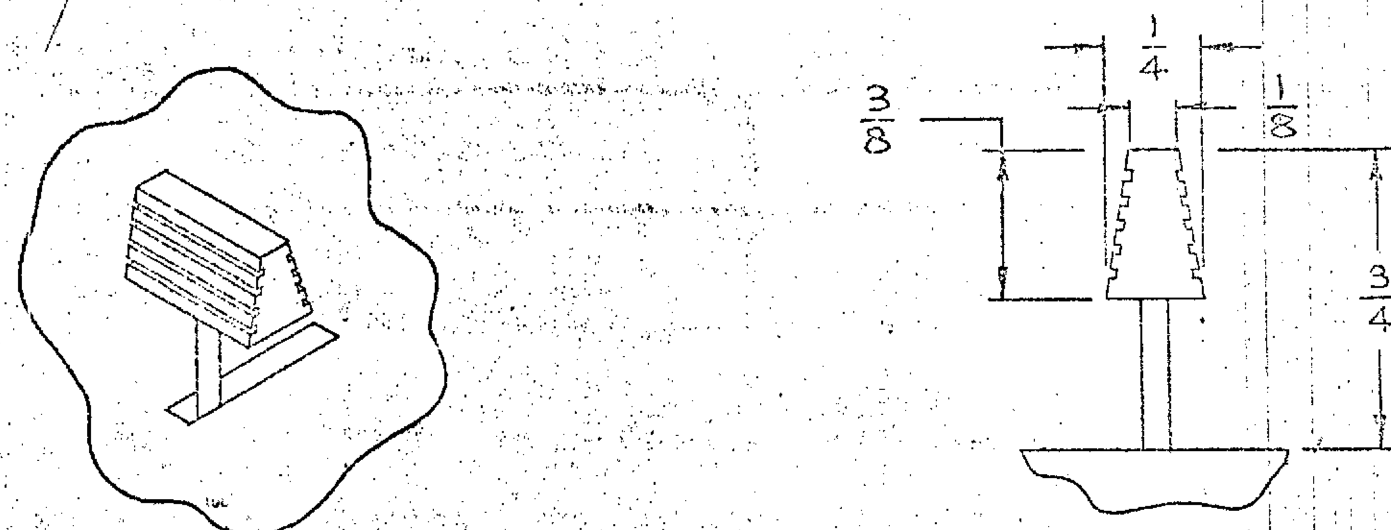
TRANSLATIONAL CONTROLLER



CONTROL # 2

CONTROL #3

PUSHBUTTON- CHANGING COUNT ON COMPUTER DISPLAYS

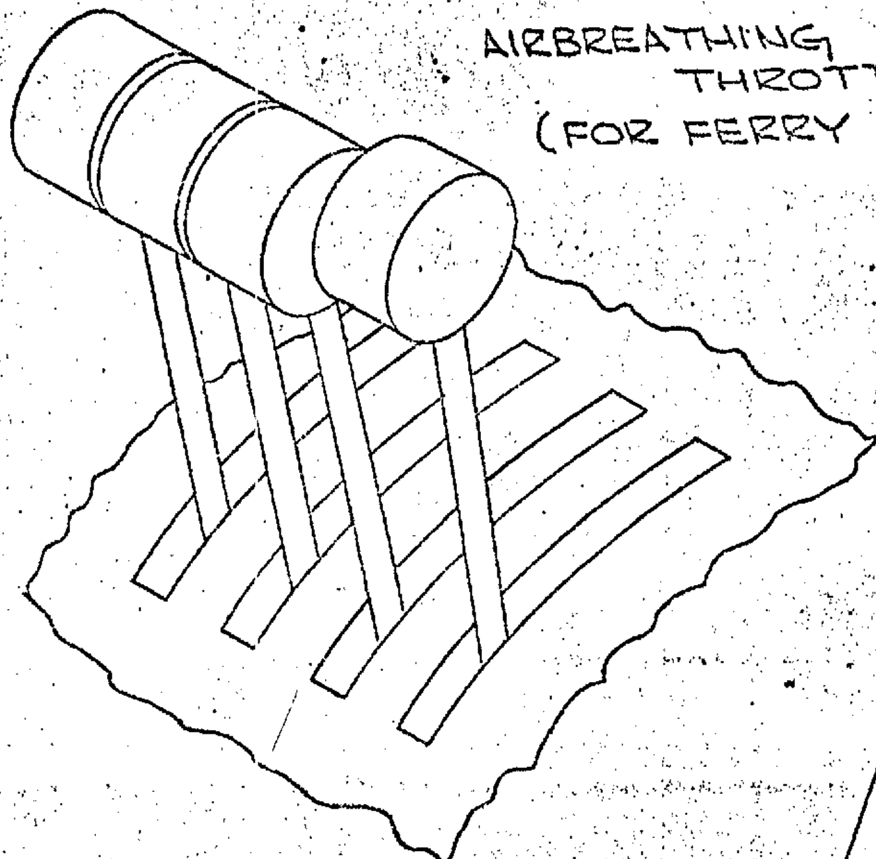


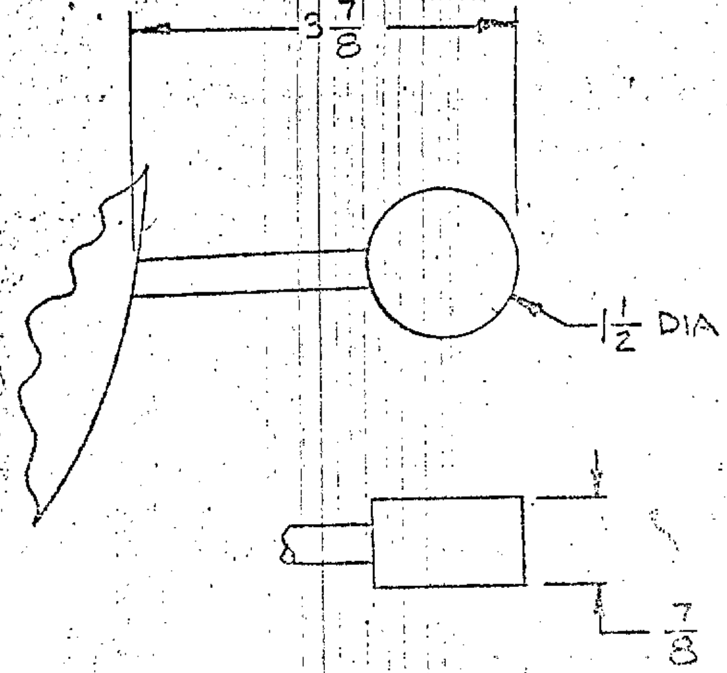
CONTROL #4

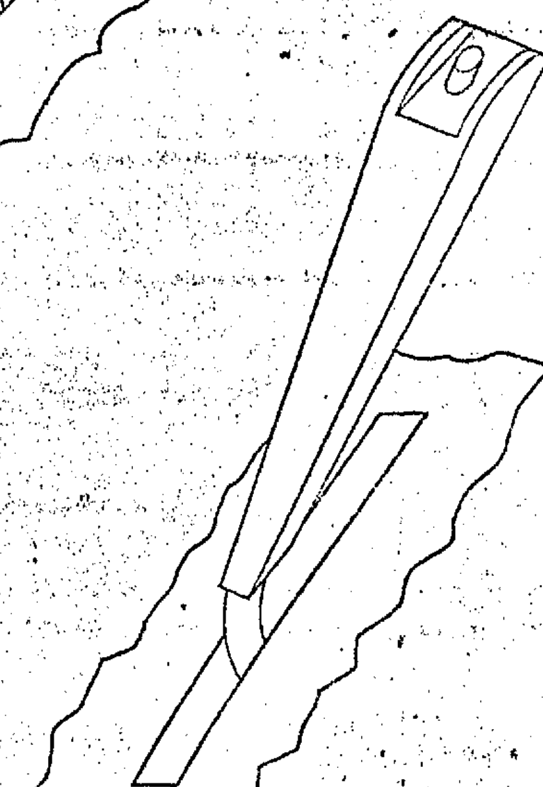
TYPICAL TOGGLE SWITCH

CONTROL #5

AIRBREATHING ENGINE
THROTTLE
(FOR FERRY FLIGHTS)

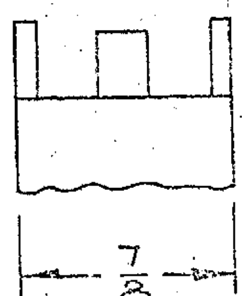






CONTROL #6

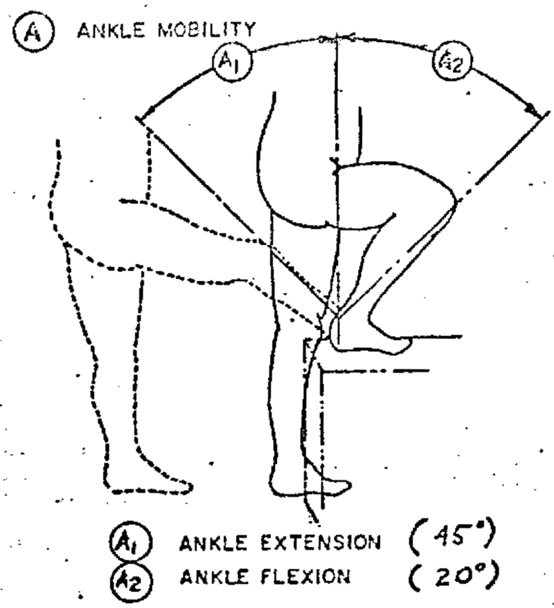
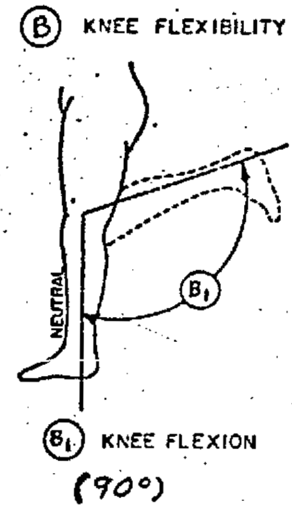
SPEED BRAKE CONTROL

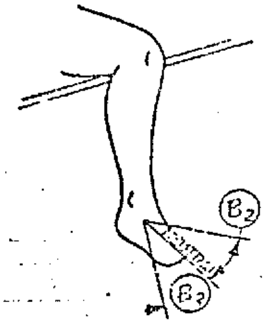
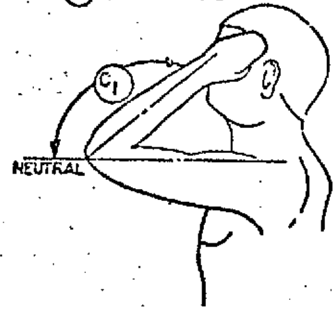
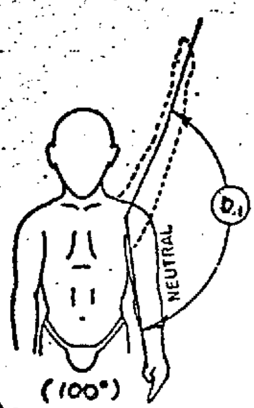


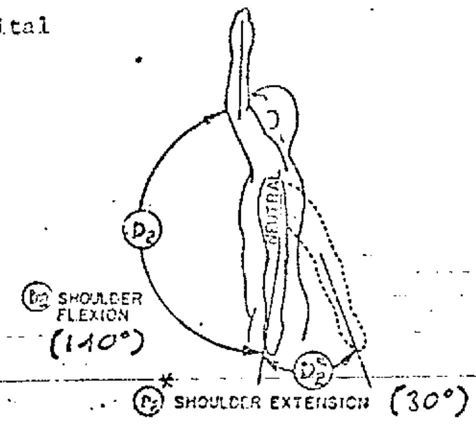
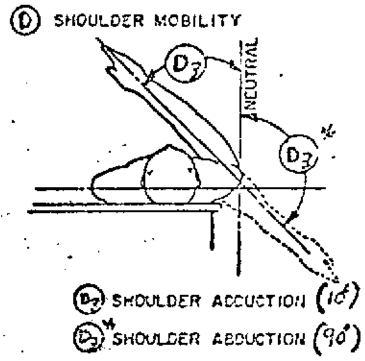
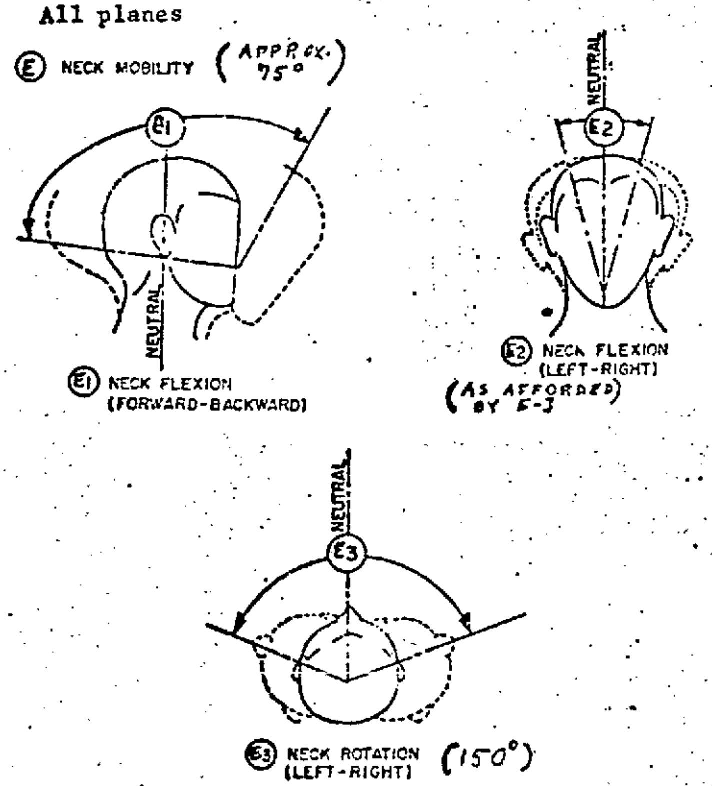
Mobility Requirements for Pressure

Suits (IV or EV) to Fly/Operate

the Shuttle Craft (NAR Mockup, 8/11/72)

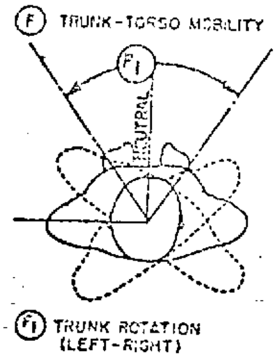
JOINT	PLANE	COMMENTS
A. Ankle	1. Sagital 	Ankle extension or "toe down" mode is required for pilot/co-pilot re-entry and descent of vehicle only when pilot decides to over-ride computer (similar to LM landing).
	2. Frontal 3. Transverse	No requirements for "dual axis" or gimbal joint exist. Ankle rotation/ad-duction/abduction not required.
B. Knee	1. Sagital 	Long term comfort at 75-90° is required in the pilot/co-pilot couch. Launch position is the worst case, but should be in the un-pressurized mode.

	2. Transverse  KNEE ROTATION (B2) MEDIAL (B3) LATERAL	Knee rotation (lateral/ medial) is not required
C. Elbow/Arm Bearing	1. As shown (sagital) (C) ELBOW MOBILITY  (100°) (C1) ELBOW FLEXION	Arm bearing is required (shoulder rotation).
D. Shoulder	1. Frontal (lateral)  (100°) (D) SHOULDER MOVEMENT (LATERAL-MEDIAL)	A great number of switches are located on an overhead panel located between the two pilots requiring upward reach not achievable in the sagital plane alone. At this time, many are inaccessible to the nude body and NAR envisions the pilot in a loose fitting seat harness "floating up (O-G only). to perform these actuations. Actually, as much upward reach as can be provided will be needed here with a joint neutral aimed more toward the constant "arm rest spread mode" for "joy stick" operation.

	2. Sagital 	Bearings are required to accomplish the expected tasks.
	3. Transverse 	Primary crossreach is required for possible use of <u>both hands</u> to actuate switches on central control panel. Overhead switches not nearly as mobility critical.
E. Neck	**All planes** 	Although the suit does not require neck mobility, the man must be afforded an extremely wide visual range. An open clear bubble is highly desirable. Good overhead as well as forward and "down to the sides" visibility is mandatory.

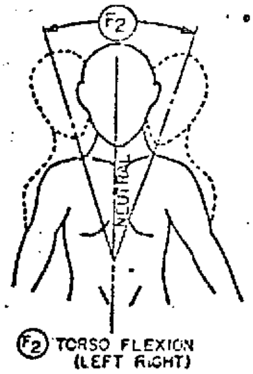
F. Waist

1. Transverse



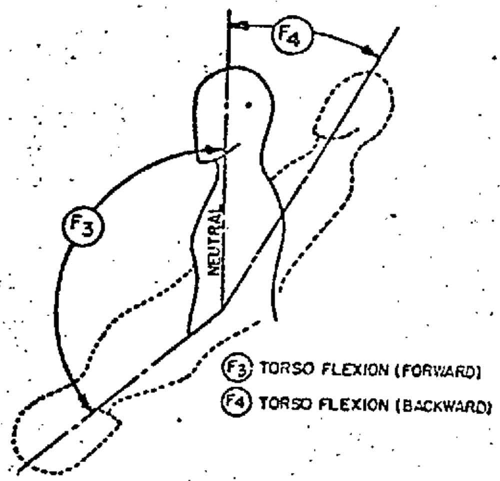
No definite requirement, however, a waist bearing could be helpful for visibility and improved upward reach toward side locations from fixed couch (depends much on loose harness).

2. Frontal



Not a requirement but again desirable for reaching switches/panels down to the sides of the suits.

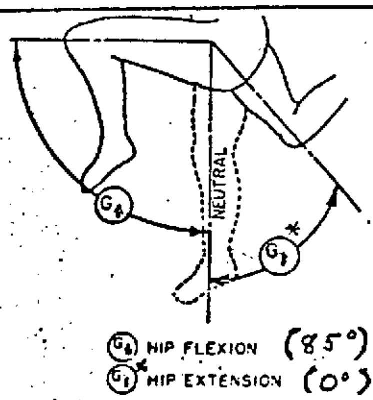
3. Sagital



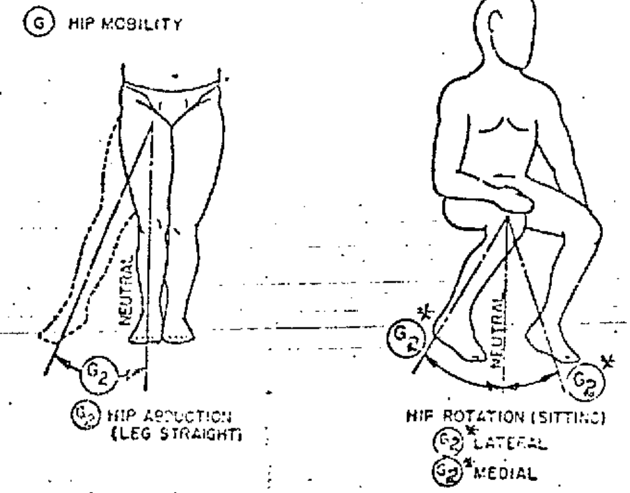
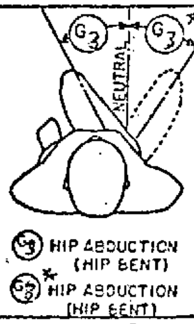
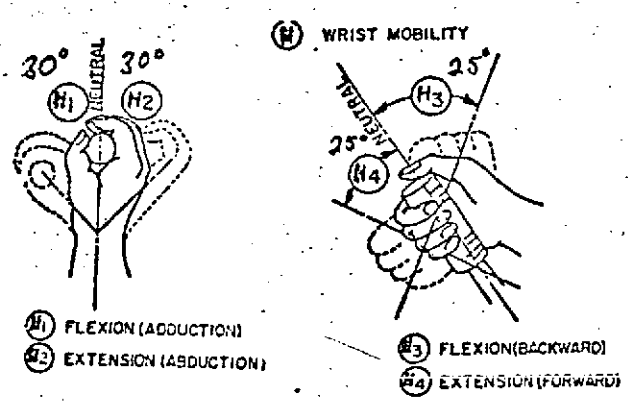
Seated couch position should be attained via biased hip joint.

G. Hip

1. Sagital



Good hip mobility is a definite requirement for ingress/egress and particularly long term seated comfort. Either the hip joint itself or the torso thigh openings should be oriented toward (perhaps only 20°) the seated mode.

	2. Frontal 	Neither rotation nor abduction are requirements at this time.
	3. Traverse 	No requirement at this time. Foot pedal spacing (2 each) is same as standard aircraft .
H. Glove	1. Wrist (see below)	Main use will be for "joystick controls". Smooth actuation/ comfort should be essential. Normal supination/pronation requirements will require a wrist bearing.
	2. Finger (Flexion only) 	Should be comfortable @ 80°- 90° holding "joystick control". <u>All</u> fingers should meet this requirement. Particularly the index finger should be comfortable and stable @ 0°- 5° (no bend) for push button switch operation on the forward center control panel. These recessed switches are approx. 3/8" x 3/8" squares and should not be too small for insertion of the pressurized finger at 8 PSID. One "tee

	2. Finger (Flexion only - Cont'd)	handle" control fits between the middle and index fingers and requires a finger spread of approx. 1/2" at the 2nd metacarpal, first 2 digits. All toggle switches were of spaded (or coined) design and can be actuated without a meeting of thumb and first digit. First or third metacarpal mobility was not a definite requirement, however, some bias (approx. 20°) is desirable.
	3. Thumb (Flexion/Extension)	Must comfortably grasp about standard Apollo CM type "joystick controls" maintaining position comfortably. An extension/rotation (toward first digit) action is required to depress a 1/8" diameter bottom mounted on top of a joystick with the metacarpal in place around the "joystick". Ballooning of palm should be limited to approximately that in Apollo.

IV PILOT/COMMANDER GLOVE DEXTERITY

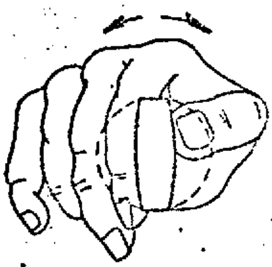
I. TYPES OF HAND AND/OR FINGER PREHENSION

PALMAR — TIP — LATERAL — GRASP



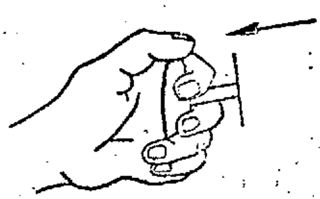

PALMAR	TIP	LATERAL	GRASP
RELATED TASKS 1. WRITING 2. USING ROTARY	RELATED TASKS PICKING UP SMALL OBJECTS	RELATED TASKS 1. USING ROTARY 2. USING TOGGLE SWITCH	RELATED TASKS 1. USING HAND CONTROLLER AND LEVERS 2. USING HANDHOLD AND HANDRAILS 3. LOCKING AND UNLOCKING AIRLOCK HATCHES 4. INGRESS AND EGRESS FROM COUCHES

II. OTHER TYPES OF REQUIRED HAND-FINGER OPERATIONS

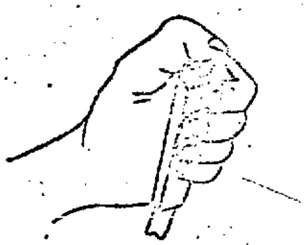


HAND ROTATION (WITH LATERAL PREHENSION)

FINGER (PUSHBUTTON OPERATIONS)



FINGER
1. PULLING OPERATIONS
2. ROTATING OPERATIONS



THUMB (BUTTON OR THUMBWHEEL OPERATIONS)

HAND AND FINGER TASKS

ADDITIONAL SUIT DESIGN IMPACT

A. The spacecraft foot pedals for rudder control does not require a "soft touch" when operating the control. Therefore a thick boot sole may be used in the suit design.

B. It would be beneficial for the pressure suit to be slightly bias toward a seated attitude which will provide long term (5-8 hours) pressurized comfort in the couch during a contingency return.

C. An extensive range of visibility is required during a contingency if the spacecraft computer system becomes inoperative. In this case the crewman will be required to fly the spacecraft manually, utilizing the numerous switches and controls located overhead and on the right and left hand sides.

ATTACHMENT I

FABRIC, NOMEX/PRD-49

5.25 OZ/YD^2

REV LTR	ECR / O NO	PREP BY	CKD BY	DES ENG	BRIEF DESCRIPTION
					Initial Release

DWG TITLE		
FABRIC, NOMEX/PRD-49, 5.25 OZ/YD^2	PREP	
	CKD	
	DESIGN	
	PROJ	
	Q & R	
DWG NO	SHEET 1 OF 4	MANU
	REV	CUST

1.0 SCOPE

This specification covers a 5.25 oz/yd^2 blended Nomex/PRD-49 woven cloth.

2.0 APPLICABLE DOCUMENTS

2.1 Federal Standard 191 - Textile Test Methods.

3.0 REQUIREMENTS

3.1 Material

3.1.1 The PRD-49 used in the manufacture of this cloth will be 200 Denier 134 Filament, Type IV.

3.1.2 The Nomex used in the manufacture of this cloth will be 200 Denier 100 Filament, color white.

3.2 Weave

The weave pattern shall be $\frac{2}{2}$ twill.

3.3 Warp Arrangement

The warp will be constructed with an 8:2 end ratio with 8 ends of PRD-49 and 2 ends of Nomex.

3.4 Filling Arrangement

The filling will be constructed of 100 per cent PRD-49.

3.5 Physical and Chemical Properties

The physical and chemical properties of the finished cloth shall conform to Table I and subparagraphs thereto.

- TABLE I - PHYSICAL PROPERTIES -

Characteristic	Value
Weight (oz/yd^2)	5.25 $\pm$ .2
Tensile Strength (lbs.)	
Grab Method	
Warp	750 Min.
Fill	750 Min.
Ravel Strip Method	
Warp	630 Min.
Fill	630 Min.

- TABLE I (cont'd.) -

Characteristic	Value
Tear Strength (lbs.)	
Tonque Tear	
Warp	50 Min.
Fill	50 Min.
Elongation (%)	
Warp	15 Max.
Fill	10 Max.
Yarns Per Inch	
Warp	113 ± 2
Fill	71 ± 2
Yarn Denier	
Warp	
PRD-49	200/134
Nomex	200/100
Fill	
PRD-49	200/134

3.5.1 Width

The fabric width shall be as specified on the Purchase Order.

3.5.2 Flammability

The fabric shall not burn.

3.5.3 Finish

The cloth shall be scoured and wrinkle free.

3.5.4 Workmanship

The finished fabric shall be of high quality, clean and free of all imperfections detrimental to application and appearance.

4.0 QUALITY ASSURANCE PROVISIONS

4.1 Responsibility for Inspection

Unless otherwise specified in the purchase order, the supplier to ILC Industries, Inc., is responsible for the performance of all inspection requirements as specified herein.

4.2 Quality Conformance Inspection

The examination and the tests comprising quality conformance inspection are left to vendor choice.

4.2.1 ILC Industries, Inc., reserves the right to inspect any or all of the requirements of this specification.

5.0 PREPARATION FOR DELIVERY

5.1 The finished material shall be marked and packaged for shipment in accordance with good commercial practice to prevent damage during exposure to normal transportation environments.

- ATTACHMENT 2 -

TEST RESULTS

FABRIC, NOMEX/PRD-49, 5.25 OZ/YD^2

ILC Test Number 06-1-2311-02

CHARACTERISTICS	RESULTS	REQUIREMENTS
Weight (oz/yd^2)	5.24	5.6 Max.
Tensile Strength (lbs.)		
Grab Method		
Warp	885	800 Min.
Fill	803	800 Min.
Ravel Strip Method		
Warp	737	630 Min.
Fill	753	630 Min.
Tear Strength (lbs.)		
Tongue Tear		
Warp	66	50 Min.
Fill	58	50 Min.
Elongation (%)		
Warp	13.6 %	5 Max.
Fill	6.7 %	5 Max.

1/4", 1/2" TAPES AND WEBBINGS

ILC TEST NUMBER 06-1-2311-02

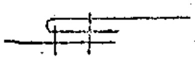
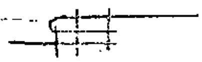
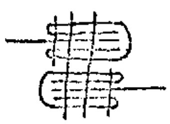
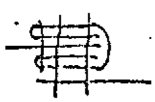
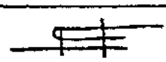
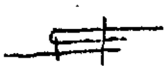
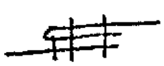
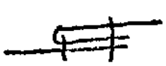
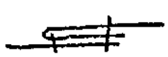
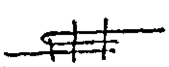
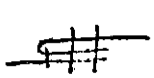
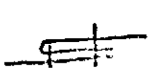
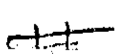
	BREAKING STRENGTH (lbs.)	ELONGATION (%)
1/4" Tape, Short Float with Stuffers	820	22.7
1/4" Tape, Long Float with Stuffers	1,027	17.5
1/2" Tape, Long Float with Stuffers	1,570	21.0
1/4" Tape, Long Float No Stuffers	790	18.8
1/2" Tape, Short Float With Stuffers	1,530	20.8
1/2" Tape, Long Float With Stuffers	1,570	21.0
1/2" Tape, Short Float No Stuffers	1,337	24.4

200, 400 DENIER, PRD-49 SEWING THREAD

ILC TEST NUMBER 06-1-256-01

CHARACTERISTICS	200 DENIER SEWING THREAD	400 DENIER SEWING THREAD
Breaking Strength (lbs.)	30.6	60.6
Elongation (%)	6.7	7.3

PRD-49 SEAM STRENGTH TESTS

ITEM NO.	SEAM TYPE	SEAM SIZE	THREAD	SIZE OF EDGELOCK	FAILURE LBS/IN	FAILURE MODE
3		1/4	400 D	1/8	327.5	Fabric
1		1/2	400 D	1/8	377.5	Fabric
2		1/2	400 D	1/8	487.5	Fabric
15		Tear in Fabric			495	Fabric
			SCYE SEAM			
1		3/8	200 D	1/8	202.5	Stitch
2	Same	3/8	400 D	1/8	255	Fabric
3		3/8	400 D	1/8	360	Fabric
4	Same	3/8	200 D	1/8	222.5	Stitch
12		1/2	200 D	1/4	197.5	Stitch
10		1/4	200 D	1/4	232.5	Stitch
11		1/2	200 D	1/4	327.5	Stitch
6		1/4	200 D	1/8	202.5	Stitch
5		1/2	200 D	1/8	230	Stitch
14		1/2	200 D	1/8	407.5	Stitch
7		1/2	400 D Join 200 D Top	1/4	417.5	Top Stitch Fabric at Join
4		1/2	400 D Join 200 D Top	1/8	430	Top Stitch Fabric at Join
9		1/4	400 D	1/4	325	Fabric
8		1/2	400 D	1/4	360	Fabric
13		1/2	400 D	1/4	500	Fabric

ATTACHMENT B

SYNOPSIS OF MATERIALS AND PROCESSES TESTING

ATTACHMENT B
SYNOPSIS OF MATERIALS AND PROCESSES TESTING

1. Visor Materials Development - Creep Testing

   Flexible PVC candidate visor material were evaluated for creep characteristics under selected loads at both RT and 100°F.

2. Dead Load Creep Test - .060" Lucolite Flexible PVC

   .060" Lucolite was evaluated for creep characteristics at various levels of loading from 5 to 46 lb. @ 82°F. 46 lb. loading was equivalent to 16 PSI internal helmet proof pressure.

3. Restraint Fabric to Aluminum Plate - Stitching Evaluation

   Nylon restraint material was attached to aluminum plate using various stitching techniques and evaluated for seam strength.

4. Perflex "E" Bladder Material - Hydrolytic Stability Testing

   Perflex "E" was cycled through water immersion and drying periods. Samples were tested for retention of physical properties after specified interval of exposure.

5. Perflex "E" Versus Neoprene - Oxygen Bomb Ageing

   Physical properties were evaluated after specified intervals of exposure to determine shelf life of Perflex "E" relative to Neoprene.

6. Perflex "E" - Compatibility with Lubricants

   Ageing tests were conducted to determine the effect of Krytox grease and G-300 silicone lubricants on Perflex "E" and qualify these materials as bladder lubricants to lessen bending torque in joints.

7. Perflex "E" - Bladder Material - Urine Exposure Tests

   Ageing tests were conducted to determine the effects of human urine on the properties of the bladder material.

8. Perflex "E" - Bladder Material - Perspiration Exposure Tests

   Ageing tests were conducted to determine the effects of perspiration on the properties of the bladder material.

9. Helmet Visor to Bladder - Heat Sealing Evaluation

Heat sealed seams of candidate visor materials to the Perflex "E" Bladder material were evaluated for tensile and peel characteristics.

10. Perflex "E" Bonding to Stainless Steel

Adhesion parameters and surface treatment for SS were evaluated for bonding the bladder to joints.

11. Helmet Visor to Restraint Fabric Attachment

Stitching techniques were evaluated for attachment of the PRD-49 restraint fabric to the soft visor.

12. Physical Property Evaluation of Dipped Perflex "E" for Glove Bladders

Tensile and tear properties were determined on Perflex "E" dip plate samples.

13. Restraint Fabric to Aluminum Stitching Evaluation

Breaking Strength was determined on stitched seams of PRD-49 to aluminum plate.

14. Helmet Visor to Bladder Bonding Evaluation

AF 770 Urethane adhesive with and without Hylene M-50 primer was evaluated for bonding the Perflex "E" bladder material to the soft helmet visor (Lucolite).

15. PRD-49 Webbing to Stainless Steel Stitching Evaluation

200 and 400 denier PRD-49 thread was evaluated for stitching 17-4 PH SS to 1/2 PRD-49 webbing.

16. PRD-49 Thread Tensile Tests

Breaking strength of PRD-49 200 and 400 denier thread was evaluated.

17. PRD-49 Webbing Attachment to Slotted Stainless Steel

PRD-49 1/4" webbing, looped through slotted SS and stitched, was evaluated for breaking strength.

18. Perflex "E" to Perflex "E" Bonding Evaluation

N-136 Neoprene adhesive was evaluated with and without Hylene M-50 primer for bonding the Perflex "E" bladder material to itself. The use of N-136 in lieu of AF 770 urethane permits peeling open the seams using toluene without damaging the bladder.

19. Bladder Material - Temperature and Humidity Ageing

Ageing tests are still in progress on Perflex "E" film at 100°F and 100% RH. DuPont Company data has indicated that 100% humidity degrades polyester base polyurethane more rapidly than immersion in water. In addition, elevated temperatures accelerate the degradation caused by humidity exposure.

After 5 months continuous exposure of the Perflex "E" to 100°F and 100% RH, no significant change in tensile and tear properties has been evident.

ILC INDUSTRIES, INC.

INTER OFFICE CORRESPONDENCE

To: R. Wise

Office: Project Engineering Materials Group

From: Vito Accetta

Date: January 4, 1973

Subject: SHUTTLE SUIT - HELMET VISOR DEVELOPMENT

The attached test report, M-PC-001, represents preliminary search and evaluation of candidate materials for use as a visor.

VA/bk

cc: J. Rayfield
P. Schneider
J. Scheible
J. McMullen
A. Gross
G. Alexandroff
R. Hahn

Cover only one subject on each memorandum.

TITLE: Visor Development - Creep Testing

TASK: X25-852-X00

DATE: January 3, 1973

TEST NO: M-PC-001

ABSTRACT: Various materials were examined for use as a flexible visor in the helmet of the shuttle suit. Repetitious proof pressure testing of the suit at 16 PSI appears to establish the most difficult requirement. Preliminary long term test loading of the candidate materials was accomplished with a dead-load apparatus, and pressurization of vacuum formed hemispheres. A guide line of no creep (permanent deformation) experience after five (5) hours at 100°F and 16 PSIG loading, was set as a result of the Phase "A" report of the Shuttle Suit Program.

SUMMARY: None of the materials tested could meet the guide line requirement of no creep when tested at 100°F; however Hedwin sheet had favorable results when tested at room temperature.

TEST ARTICLES: Flexible PVC (plasticized polyvinyl chloride)

a) .040" Regalite by Tenneco

b) .060" Regalite by Tenneco

c) .040" Hedwin by Tenneco

TEST DOCUMENT: R & E Test Report No. 2293-04

R & E Test Report No. 2355-05

R & E Test Report No. 3003-17

TEST PROCEDURE: Preliminary evaluation of several different materials when vacuum formed into hemispherical bubbles and pressure tested left but two possible candidates, Regalite and Hedwin sheet, both manufactured by Tenneco. These materials were then dead loaded with 46 lbs/in (equivalent to 16 PSIG) at 100°F for 5 hours. Neither material proved satisfactory; however, the stiffer (higher modulus) Hedwin sheet was tested in greater detail to possibly attain a theoretical thickness at which it would be acceptable.

RESULTS: See Creep Testing Table

CONCLUSIONS: Hedwin in any acceptable thickness (250 mils or less) is highly susceptible to permanent set when tested at 100°F. . This material exhibited no creep when tested at room temperature and 20 lbs/in (equivalent pressure = 7.5 PSIG); but the higher temperature requirement is extremely limiting. Continued search is under way for an acceptable material, but prospects look dim. A hard visor seems to be the only alternative, unless a waiver of the 100°F testing parameter is obtained.

CREEP TESTING

	1 Min.	30 Min.	1 hour	2 hours	3 hours	4 hours	5 hours	Permanent Set *1
	%	%	%	%	%	%	%	%
A) $100^{\circ}F$								
1) 46 lbs/in								
a) .040" Regalite - Machine Dir.	38		81	84	84[2*]	84[2*]	84[2*]	23
b) .040" Regalite - Transverse Dir.	38		97	106	106[2*]	106[2*]	106[2*]	31
c) .060" Regalite - Machine Dir.	25		66	72	84	88	88[2*]	34
d) .060" Regalite - Transverse Dir.	25		62	72	84	88	91	34
e) .040" Hedwin - Machine Dir.	13		47	56	62	66[3*]	66[2*][3*]	34
f) .040" Hedwin - Transverse Dir.	13		53	59	81			34
2) 20 lbs/in								
a) .040" Hedwin - Machine Dir.	6	38	44	50		72		
b) .040" Hedwin - Transverse Dir.	12	38	44	50		75		
3) 6 lbs/in								
a) .040" Hedwin - Transverse Dir.	0	12	12	19		25		16
4) 3.5 lbs/in								
a) .040" Hedwin - Machine Dir.	0	3	6	6		12		3
B) Room Temperature $\approx 76^{\circ}F$								
1) 20 lbs/in								
a) .040" Hedwin - Machine Dir.	0		0	0	0	0		0
b) .040" Hedwin - Transverse Dir.	0		0	0	0	0		0

*1 Percent sample exhibits permanent set or elongation approximately two (2) weeks after testing.

*2 Dead load mechanism believed to have bottomed out, thus true reading suspected to be higher.

*3 Sample slipped from retaining gripes.

HELMET MATERIAL

DEAD LOAD CREEP TEST

.060" Lucolite - 1" wide samples
Creep (inches) @82°F
(1" gage length)

	Load				
After	5 lb.	10 lb.	20 lb.	30 lb.	46 lb.
1 minute	0	1/32	3/32	3/16	3/16
30 minutes	1/64	1/16	5/32	9/32	11/32
1 hour	1/32	3/32	5/32	11/32	3/8
2 hours	1/32	3/32	3/16	3/8	15/32
3 hours	1/32	3/32	7/32	3/8	1/2
4 hours	1/32	3/32	7/32	3/8	1/2
5 hours	1/30	3/32	7/32	13/32	17/32
After 24 hours Recovery Period	0	0	0	1/32	1/16

NOTE: 46 lb equivalent to 16 PSI internal pressure in spherical helmet (115 in diameter).

Title: Nylon Restraint Material to Aluminum Plate - Stitching Evaluation

Task #: X21-995-211

Date: 13 November 1972

Test #: M-ST-001

Abstract: Nylon restraint material was attached to aluminum plate using various stitch patterns to allow testing and evaluation for possible bearing attachment.

Summary: Using two (2) rows of ten stitches per inch, 1/8" apart, with 200 denier PRD-49 thread, 7 oz. nylon restraint, the fabric failed at approximately 580 lbs, with no noticeable damage to the plate or stitches.

Test Articles:

a) Nylon thread size "F"
b) PRD-49 thread 200 denier
c) 7 oz. nylon restraint fabric, blue
d) Y32" medium tempered (T3-T4) aluminum plate

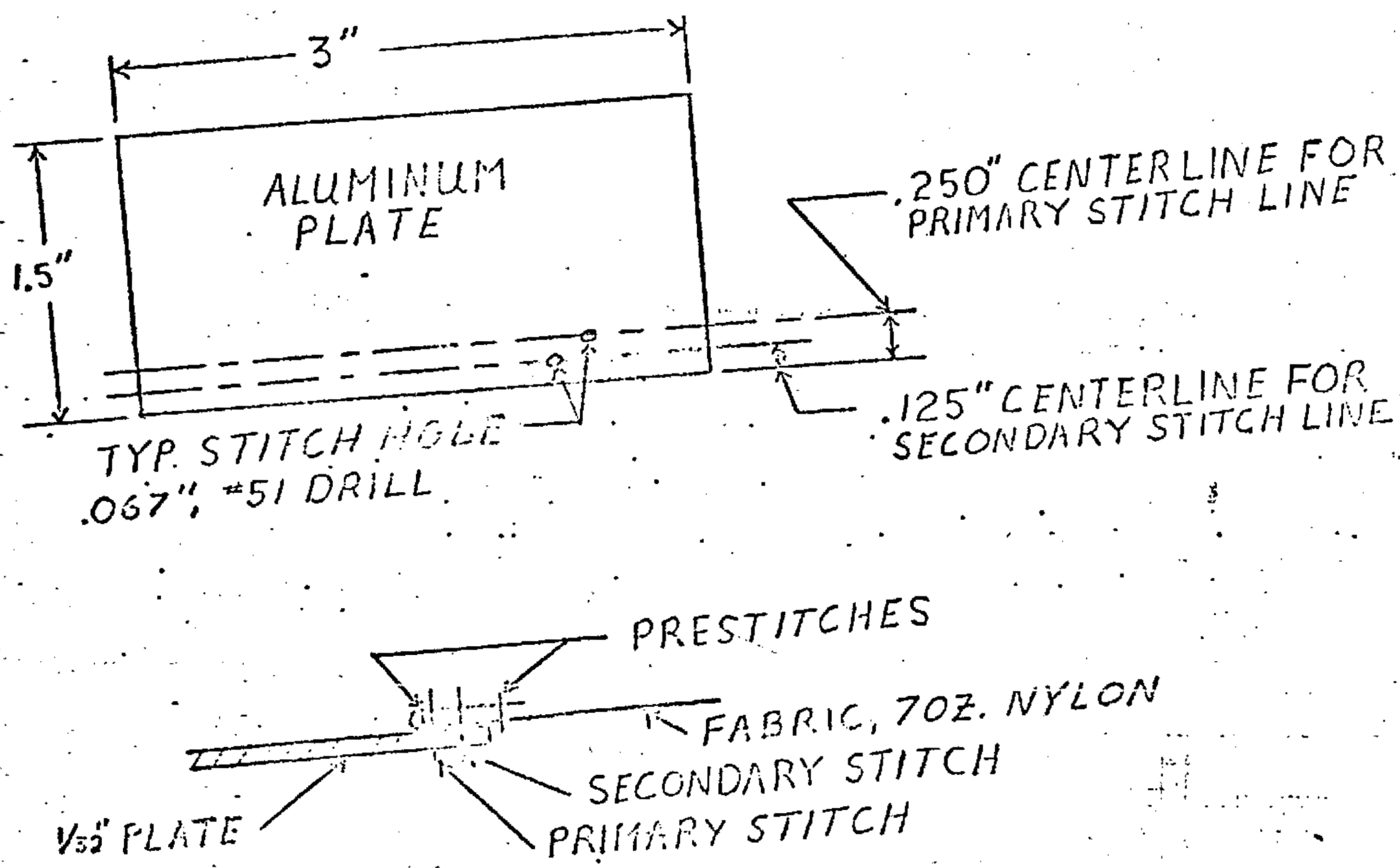


FIGURE 1

Test Document: R & E Test Request #06-1, 2315-01

Test Procedure:

The aluminum plate was pre-drilled on an upright milling machine to the required stitch pattern. The fabric was then folded and pre-stitched to obtain proper edge strength. The aluminum plate was then attached with a 111W153 Singer sewing machine, needle size 20. The illustrations shown in Figure 1 depict sample configuration. All samples were tested on the Instron testing machine, jaw travel .5" per minute, 1" grips.

Results: Seam Configuration	Average (lbs/in)
a) 5 stitches/in. primary row only nylon "F" thread	80 stitch failure
b) 5 stitches/in. primary row only PRD-47 thread	190 stitch failure
c) 8 stitches/in. primary row only PRD-49 thread	345 stitch failure
d) 10 stitches/in. primary row only PRD-49 thread	330 stitch failure
e) 6 stitches/in. both secondary and primary rows offset stitches PRD-49 thread	350 stitch failure
f) 10 stitches/in. both secondary and primary rows in line stitches PRD-49 thread	580 fabric failure

Observations:

Care should be taken to smooth all machine holes to prevent cutting of thread; however, excessive bevelling of holes tends to weaken material.

Conclusions:

Preliminary testing reveals favorable results when restraint fabric is stitched to pre-drilled aluminum plate; however, further testing is recommended to optimize stitch configuration. Sample "F" configuration appears to dictate a double in line stitch to minimize shear stress on stitches, and further allow excellent seam attachment. As in this sample, the seam was stronger than the material itself.

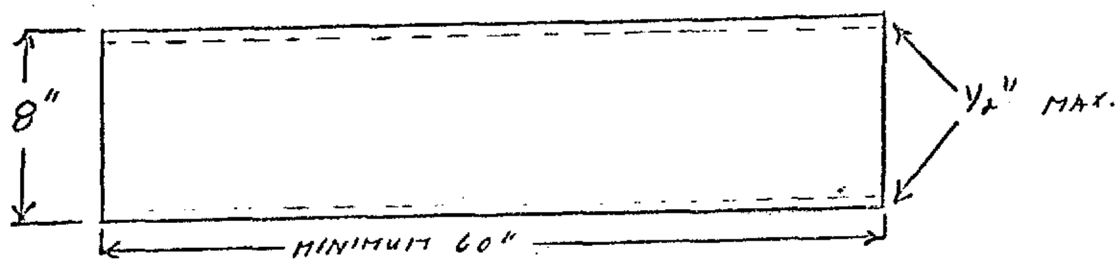
TEST PLAN

DATE: January 12, 1973

TITLE: Perflex "E" Hydrolytical Stability Testing

PURPOSE: Cycle Perflex "E" material through wet and dry environments similating WIF (Water Immersion Facility) testing.

PROCEDURE: Stitch Perflex "E" (3 MIL) to nylon restraint (3 oz.) as described below:



Roll sample piece loosely and immerse in beaker of room temperature tap water for four (4) hours. After immersion remove from soaking and air dry (use fan if necessary) for 20 hours. Immerse again in water and continue on 24 hour cycles. Leave samples immersed in water for weekends and holidays. Record all pertinent times. After one (1) week, two (2) weeks, and one (1) month of cycling, cut three (3) tensile and three (3) tear samples from the specimen roll. Remove restraint material and test Perflex "E". Compare results with testing performed on similar Perflex "E" material which has not been cycled.

WATER IMMERSION

Sample	Tensile-Modulus 300%	Ultimate	Ultimate Elongation	Tear
Control	1832	5876	485	398
7 Day	1920	5644	467	408
14 Day	1959	4878	442	433
30 Day	1748	5433	483	395

Sample	Hours Wet	Hours Dry
7 Day	90	81
14 Day	213	125
30 Day	500	244

TITLE: Aging Evaluation, Perflex "E" vs Neoprene

TASK: X21-995-X02

DATE: January 5, 1973

TEST NO: M-AG-002

ABSTRACT: Samples were tested at various stages of oxygen bomb aging, to determine an approximate shelf life for Perflex "E" relative to Neoprene. Perflex "E" is the prime candidate for bladder material in the Shuttle Suit Program with a preliminary quideline of an eight (8) year shelf life.

SUMMARY: The Perflex "E" material exhibited better over all physical properties than the Neoprene both before and after Oxygen Bomb Aging. See Table No. 3.

TEST ARTICLES:
a) Perflex "E", 10 MIL, ST17P067, Polyester, Base Union Carbide.
b) Neoprene compound, ST65N478, Goodyear.

TEST DOCUMENT: R & E Test Request No. 2326-10

TEST PROCEDURE: The uncurred neoprene stock was press molded for 30 min @ 300°F. Die "C" tensile and tear samples were cut from both the cured neoprene and Perflex "E". Testing was performed with material as is, and 96,179, and 348 hours after aging @ 176°F, 300 PSI O_2. All aged tensile samples were prestressed tc 100% elongation before insertion into the bomb. Table No. 1 gives a summary of the average values of the test results. Table No. 2 shows the percentage change of both materials at various interims during aging. Table No. 3 compares the initial and final physical properties of Perflex "E" as compared to neoprene in a percentage value.

RESULTS: See Table No. 1, 2, and 3.

CONCLUSIONS: Perflex "E" is obviously the better material. Table No. 3 clearly shows that its physical properties maintain relatively the same advantage before and after aging. Its properties after aging are still better than the neoprene's before aging. It is generally assumed that under "normal" conditions, Neoprene has a usefull life of approximately twenty (20) years; thus Perflex "E" should easily give a useful shelf life of eight (8) years. The additional advantage of being able to heat seal Perflex "E" adds to its acceptability.

If oxygen bomb aging is representative of the real world, and the chemical properties of Perflex "E" are acceptable, this material looks extremely favorable.

TABLE #1 SUMMARY OF AVERAGE VALUES

Item	Modulus (PSI) 300	500	700	Ultimate Tensile (PSI)	Ultimate Elongation (%)	Tear Strength (Lb/in)
Perflex "E"						
As received	2481	8187	---	8187	500	480
Aged 96 hrs.	598	1639	3828	5558	800	457
Aged 179 hrs.	563	1313	3099	5436	867	454
Aged 348 hrs.	448	1176	2908	5505	892	442
Neoprene						
As received	1574	---	---	1531	291	182
Aged 96 hrs.	828	---	---	1143	342	188
Aged 179 hrs.	581	---	---	1051	400	181
Aged 348 hrs.	486	---	---	903	483	195

TABLE #2 PERCENTAGE CHANGE VS ORIGINAL

Item	Modulus (PSI) 300	500	700	Ultimate Tensile Tensile	Ultimate Elongation Elongation	Tear Strength Strength
Perflex "E"						
96 hrs.	-76%	-80%	--	-32%	+60%	-9%
176 hrs.	-77%	-84%	--	-33%	+73%	-9%
348 hrs.	-82%	-86%	--	-34%	+78%	-9%
Neoprene						
96 hrs.	-47%	--	--	-25%	+18%	+3%
179 hrs.	-63%	--	--	-31%	+37%	-1%
348 hrs.	-69%	--	--	-41%	+66%	+7%

TABLE #3 PERCENTAGE ADVANTAGE OF PERFLEX VS NEOPRENE

Item	Modulus 300	500	700	Ultimate Tensile	Ultimate Elongation	Tear Strength
Before Aging	+58%	--	--	+434%	+72%	+164%
After Aging	-8%	--	--	+510%	+85%	+127%

ILC INDUSTRIES, INC.

INTER OFFICE CORRESPONDENCE

To: R. Wise

From: Vito Accetta

Subject: PERFLEX "E" COMPATIBILITY AGING EVALUATION

Office: Project Engineering Materials Group

Date: January 15, 1973

The attached Test Report M-AG-003 summarizes testing performed on compatibility of G-300 and Krytox with Perflex "E".

VA/bk

cc: D. Bethel
R. Bessette
K. Deamer
G. Alexandroff
P. Schneider
D. Rinehart
J. Scheible
J. Rayfield
J. McMullen
A. Gross
R. Hahn

TITLE: Perflex "E" Compatibility Aging

TASK: X21-852-X00

DATE: January 15, 1973

TEST NO: M-AG-003

ABSTRACT: Perflex "E" material was coated and aged with G-300 Silicone grease and Krytox fluorinated grease. The purpose behind this testing is to qualify these greases as bladder lubricants to lessen the required bending torque in joints of the Shuttle Suit Program.

SUMMARY: The two lubricants appear to be acceptable with no detrimental effects to the Perflex "E", infact, the coated specimens exhibited slightly better physical characteristics than the non-coated specimens.

TEST ARTICLES:

a) Perflex "E", 3 MIL, ST17P067, polyester base, Union Carbide.

b) G-300, silicone grease, General Electric ST53S250.

c) Krytox, fluorinated grease, E. I. DuPont ST53F382.

TEST DOCUMENT: R & E Test Request No. 2355-04

TEST PROCEDURE: Ten sets of samples (3 tensile & 3 tear) were prepared. One set tested as is, and the other nine loaded on hangers for the bomb. Three sets (group 1) were coated with G-300, and three sets (group 2) were coated with Krytox, with the remaining three sets (group 3) plain. Sample sets were then oxygen bomb aged at 176°F @ 300 PSI 02. One set from each group was removed and tested after 48 hours, 96 hours, and 7 days.

RESULTS: See Table.

CONCLUSIONS: Close observation of the results show six (6) coated values worse than the uncoated values, four (4) the same, and twenty-six (26) better. Allowing for standard test result deviations, any particular value can be proven to be within the expected limits; however, the high frequency of better values appears to prove that the coatings actually improve the aging characteristics of the Perflex "E".

	MODULUS PSI 300%	500%	700%	Ul. Ten. PSI	Ul. Elong. %	Tear St. Lb/In.
As IS	2323	7199	---	7313	503	434
48 hours						
Plain	574	1570	3524	4598	783	418
G-300	650	1685	4137	5210	775	419
Krytox	765	1915	4865	5133	717	438
96 hours						
Plain	612	1647	3869	5306	800	409
G-300	612	1647	3984	4846	750	409
Krytox	689	1685	4080	4616	730	390
7 days						
Plain	469	1379	3371	4731	816	371
G-300	478	1302	3409	4137	758	371
Krytox	689	1647	4061	5018	792	332

TEST PLAN

SUBJECT: Corrossion Resistance of Perflex "E" to Human Urine

REQUIREMENTS: Guideline - Maximum duration of exposure of the suit to any biological or other accidental catastrophy is eleven (11) days. The suit therefore should maintain structural integrity for at least this length of time after exposure to any harmful environment.

PROCEDURE: Cut six (6) samples of urethane 16" X 6". Totally submerge five (5) of the samples in urine speciment which shall be heated to 98°F ± 2°F. The remaining sample shall be tested as a control specimen. (Care should be taken to insure that all six (6) samples are cut from the same piece of yardage and that the orientation of all the samples is the same.) Remove one (1) sample 2 days, 4 days, 7 days, 11 days, and 1 month after beginning test. Sample shall be thoroughly washed in antiseptic soap solution supplied. The sample shall be wiped dry and allowed to air a minimum of 2 hours prior to testing. Testing of each sample must be done the same day the sample is removed from the urine specimen.

Perflex "E" is a "directional material", therefore, all tensile and tear samples (five (5) each for each sample) must be cut in the same direction - suggest samples be cut parallel to width (6" dimension).

URINE EXPOSURE EVALUATION

Sample	Modulus 300%	Ultimate Tensile	Ultimate Elongation	Tear St.
Control	4284	7128	442	482
2 Day	2963	6607	450	420
4 Day	2089	5445	475	389
7 Day	2806	6007	429	446
11 Day	2634	6075	470	396
30 Day	1710	5496	480	399

Water Bath 98 $\pm$ 2°F

TEST PLAN AND PROCEDURE

FOR IMMERSION OF

PERFLEX E AND TUFTANE 410

IN SYNTHETIC PERSPIRATION

MAY 22, 1973

1.0 PURPOSE

The purpose of this test is to immerse samples of Perflex-E and Tuftane 410 in a synthetic perspiration solution for evaluation, of degradation, of physical characteristics.

2.0 TEST ARTICLES

Four (4) samples will be used for this test. The first two (2) samples will be 8" X 60" pieces of Perflex-E (10 Mil). The second (two) samples will be 8" X 60" pieces of Tuftane 410. All samples will be stitched to an equal length of white nomex liner material.

3.0 PREPARATION OF SYNTHETIC PERSPIRATION

3.1 Acid Solution

NACl	- 10 gm
Latic Acid USP 85%	- 1 gm
Histidine Monohydrochloride-	- .25 gm
Disodium Orthophosphate, Anhydrous	- 1 gm

Dissolve the above materials in distilled water and then add sufficient distilled water to make a one liter solution. This solution shall have a pH of 3.5. If the pH is not 3.5, suitable adjustments shall be made with lactic acid and disodium orthophosphate or monosodium orthophosphate, or a new solution shall be prepared.

3.2 Alkaline Solution

NACl	- 10 gm
Ammonium Carbonate USP	- 4 gm
Histidine Monohydrochloride	- .25 gm
Disodium Orthophosphate, Anhydrous	- 1 gm

3.2 (Cont'd)

Dissolve the above materials in distilled water and then add sufficient distilled water to make a one liter solution. This solution shall have a pH of 8.0. If the pH is not 8.0, suitable adjustments shall be made with disodium orthophosphate, monosodium orthophosphate, or ammonium carbonate, or a new solution shall be prepared.

*NOTE - These ingredients may have to be doubled, tripled etc. to make sufficient quantity for complete immersion of the test samples.

4.0 PROCEDURE

4.1 Control - Cut ten (10) one inch samples and perform five (5) tensile and five (5) tear tests as a baseline.

4.2 Immersion - Immerse one strip of Perflex-E and one strip of Tuftane 410 in the acid solution and one each in the alkaline solution. Solutions should be kept constant at 98° F. Remove each sample at the following times; 2 hrs, 8 hrs, 1 wk. 2 wks, 4 wks and cut a piece ten (10) inches long from each sample. Allow the samples to air dry and then cut ten (10) one inch samples from each strip and perform five (5) tensile and five (5) tear tests on each set of materials.

*NOTE - All samples must be pulled on day of removal.

5.0 RESULTS

All data collected will be recorded on the applicable R & E test data sheets and then returned with the material to the test originator for further evaluation.

Philip Schneider
Test Director 5/22/73

PERSPIRATION EXPOSURE DATA

	PERFLEX "E"					TUFTANE 410				
	300% Mod (psi)	500% Mod (psi)	Ult. Ten (psi)	Ult. Elong. (%)	Tear (lb/in)	300% Mod (psi)	500% Mod (psi)	Ult. Ten (psi)	Ult. Elong. (%)	Tear (lb/in)
Control	1480	4400	5000	570	430	1170	3150	5700	620	440
ALKALINE SOLUTION										
2 hour	1130	3750	5500	610	420	1060	2620	5700	650	430
8 hour	1090	3610	5300	600	400	1000	2540	5800	650	420
1 week	980	3300	4800	600	380	1020	2510	5400	660	420
2 week	1010	3190	4700	600	380	1040	2520	5300	660	430
4 week	1270	4260	5700	600	430	1120	2940	5500	640	470
ACID SOLUTION										
2 hour	1130	3790	5700	620	420	1020	2630	5700	640	420
8 hour	1090	3720	5500	610	400	1050	2590	6000	680	420
1 week	1110	3480	5400	610	400	1000	2400	5000	680	420
2 weeks	1090	3340	4900	610	390	1040	2560	5600	650	430
4 weeks	1140	3550	4900	600	400	1110	2700	5300	640	440

HELMET HEAT SEALING EVALUATION

Seam Tensile (lb/in)

.040 Regalite/10 MIL Perflex/.040 Regalite		.040" Hedwin/10 MIL Peflex/.040" Hedwin	
1.	32.5	1.	240
2.	233	2.	10.3 (Sample Edge Nicked)
3.	27.0	3.	19.3 "
4.	18.5	4.	24.5 "
5.	30.7	5.	31.8
6.	27.5	6.	16.0 (Sample Edge Nicked)

PEEL STRENGTH (LB/IN)

.040 Regalite to .040 Regalite		.040" Hedwin to .040 Hedwin	
1.	66.0	1.	63.5
2.	69.5	2.	61.5
3.	68.0	3.	61.0
4.	75.0	4.	45.0
5.	68.0	5.	71.0
6.	70.5	6.	60.5

PERFLEX "E" BONDING TO S. STEEL (17-4 PH)

(AF 770 Adhesive)

S. S. Sand Blasted & Primed w/8% Hylene M-50 in Toluene

Lap	Shear (PSI)		Peel (lb/in)
1.	5.7	1.	6.6
2.	6.2	2.	6.5

15% Hylene M-50 in AF 770 Adhesive
(SS Sand Blasted)

	Lap Shear (lb) (1" width samples)		Peel (lb/in)
			19.6
Overlap			
1/2"	21.8	Perflex "E" Substrate Failed - Seam Remained Intact	
1/2"	26.5		
1/4"	24.5		
1/4"	27.5		
1"	31.0		
1"	25.8		

HELMET/FABRIC ATTACHMENT EVALUATION

.060" Lucolite to 5.25 oz. PRD-49

(200 Denier Thread)

Breaking Strength (lb/in)

(Machine Stitched)

6 stitches/inch		8 stitches/inch		10 stitches/inch	
1.	327	1.	335	1.	317
2.	325	2.	337	2.	320
3.	337	3.	335	3.	322

HAND STITCHED W/DOUBLED 200 DENIER PRD THREAD

Breaking Strength - 160 lb/in

.100" Lucolite to 5.25 oz. PRD-49

200 Denier Doubled Thread

Breaking Strength (lb/in)
(hand stitched)

1. 280

2. 283

3. 330

PERFLEX "E" DIPPING EVALUATION

(For Glove Bladders)

Tensile & Tear Properties of Dip Plates
(10 MIL)

	100% Mod.	200% Mod.	300% Mod.	400% Mod.	500% Mod.	Ultimate Tensile	Ultimate Elongation	Tear Strength
1.	460	707	1097	1734	3079	4460	610	367
2.	536	732	1265	2244	3805	4439	550	409
3.	461	703	1187	2022	3428	4527	575	333
4.	448	747	1121	1832	2878	3290	550	353
5.	528	720	1160	1840	3040	4040	550	350
Avg.	485	722	1167	1934	3246	4151	567	362

ALUMINUM TO PRD-49 95.25 oz) STITCHING EVALUATION

Aluminum drilled - 8 - 9 stitches per inch

(Hand stitched w/400 denier PRD-49 thread)

<u>4" Width Sample</u>

Breaking Strength (lb)

1. 930 (232 lb/in)

2. 750 (195 lb/in)

HELMET VISOR/BLADDER BONDING EVALUATION

AF 770 Adhesive

Perflex "E" (10 MIL) to Lucolite

No Primer		Perflex & Lucolite Primed w/8% Hylene M-50 in Toluene	
Peel (lb/in)	Lap Shear (PSI)	Peel (lb/in)	Lap Shear (PSI)
1. 16	1. 35.5	1. 23.0	1. 28.5
2. 16.2	2. 34.5	2. 17.5	2. 27.5
	3. 36.0		3. 29.5

All Samples - Perflex "E" Failed - Seam Held

SEAM TENSILE TESTS

17-4 SS to 1/2" PRD-49 Webbing

200 Denier PRD-49 Thread

	Tensile Load (lbs)	Mode of Failure
No. 1.	825	Stitching Failed
2.	930	Stitching Failed
3.	625	Stitching Failed

400 Denier PRD-49 Thread

No. 1.	945
2.	1000
3.	980

THREAD TENSILE TESTS (PRD-49)

Breaking Strength (lbs.)

200 Denier	400 Denier
25.5	60.0
25.3	60.0
26.3	60.5
24.8	62.0
25.8	60.0
25.5 lb (Avg.)	60.5 lb (Avg.)

METAL TO WEBBING EVALUATION

SS Buckle with 1/4" PRD-49 Webbing

Looped & Stitched

Breaking Strength (lbs.)

1. 626 (Webbing Failed)

2. 515 (Webbing Failed)

3. 490 (Webbing Failed)

PERFLEX "E" BONDING EVALUATION

N-136 Neoprene Adhesive

Perflex "E" to Perflex (No Primer)

Peel (lb/in)	Lap Shear (PSI)
4.7	13.4
4.7	13.9
5.4	12.9
4.9 Avg.	13.4 Avg.

PERFLEX "E" TO PERFLEX "E" (8% Hylene-M-50 Primer)

Peel (lb/in)	Lap Shear (PSI)
6.5	25
6.3	29.5
6.8	27.0
6.5 Avg.	27.2 Avg.

3.9 SIZING

Though the Phase "B" prototype suit assembly will be indivudually sized to fit a specific NASA approved subject, current efforts include development of suit sizing adjustments to accommodate additional subject. Design goals include minimal restriction on normal body movements and minimum overall bulk. The background research for the sizing program required related programs to a large extent, and is reported as Shuttle Suit Sizing Study, a copy of which is attached.